



TITLE:

Study of Advanced Pipeline Transportation Systems(Dissertation_全文)

AUTHOR(S):

Kasai, Takashi

CITATION:

Kasai, Takashi. Study of Advanced Pipeline Transportation Systems. 京都大学, 2005, 博士(工学)

ISSUE DATE:

2005-03-23

URL:

<https://doi.org/10.14989/doctor.k11552>

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Takashi Kasai

December 2004

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by

Takashi Kasai

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**A dissertation submitted to
Graduate school of engineering, Kyoto University
in partial fulfillment of requirements for the degree of
Doctor of Engineering**

ABSTRACT

The development of modernized pipeline transportation system started in USA about in 1925, and nowadays it is one of the most safe and economical conveyance methods of natural gas, oil, water and other contents including solid articles accumulating plenty of achievements in the world.

In Japan there have been also spreaded grand scale pipeline systems especially in the fields of natural gas and water, moreover the further development is expected to creat a more comfortable and ecological society in the future.

Advanced technical proposals have been made in this paper in order to achieve such a significant theme concerning pipeline transportation systems, some of which have been already executed in practical use.

As practical proposals toward the establishment of safer and more ecomomical natural gas pipeline systems, advanced natural gas construction systems and high-pressure natural gas supply system have been developed, which will make further utilization of natural gas as a national clean energy.

In the field of LNG transportation, the sure and reasonable new piping and pipeline system has been also developed using high-alloy welding and utilization technology.

From the viewpoint of energy saving, heat energy generated in such as CGS system must be fully used around the heat source. To make the transportation of high temperature water economically, the new heat insulation pipeline system has been developed.

Because not only construction but maintenance is a very important theme of pipeline technology from now on, maintenance technology and devices have also developed to ascertain the safety and soundness of existing pipeline. Furthermore, economical renewal ways of existing pipeline have been developed.

These developments concerning pipeline transportation systems will surely make efficient energy utilization which is the common theme for the people in the world.

ACKNOWLEDGEMENTS

My greatest gratitude goes to my supervisor, Professor Koichi Ono, for giving me the opportunity to study in graduate school of engineering, Kyoto University, and kindly encouraging me to think deeper about my reseaches. I appreciate all his supports, avdices, and guidances during my school days because I learned a great deal from him and honored to be one of his students for three years.

My next thanks go to Professor Hirokazu Iemura for his generously advising me to complete my dissertation from the viewpoint of lifeline engineering. My thanks also go to Assistant Professor Kunimasa Sugiura for guiding me in the field of steel structure engineering.

After finishing the graduate course of Kyoto University in 1978, I have been with the Engineering Division of Sumitomo Metal Industries, LTD. All of my reseaches are derived from the experiences for twnty-five years with splendid seniors and colleagues fortunately. I would also like to thank to all the partners for giving me valuable advices and reliable cooperations.

I also wish to exress appreciation to Mr. M. Ikebe, Mr. J. Nishio and Mr. I. Hoshino for distinguished advices on the principal and application of the welding and ultrasonic testing technology.

I would also like to thank Mr. M. Tsuru and Mr. T. Kitamura for their kind advices on the pipe coating and its inspection technology.

Lastly I express my deepest appreciation to Mrs. Yoshiko Kasai and Mrs. Sumiko Kasai for their strong encouragement and support to my challenge of the enterance and the study through all my activities.

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Chapter 1 Introduction

The word "Pipeline" is recently pretty popular not only for those in oil and/or gas companies but also for common people.

In Japan, however, almost all the people never know the role and function of pipeline because of its special geometical reasons.

Specifically, as the whole land of Japan is surrounded by the sea, the progress of pipeline is very slow and narrow compared with that in USA, Europe and other foreign countries. In that sense, so far as the field of pipeline is concerned, there are distinct differences between Japan and other industrial countries in the world.

Therefore, in this chapter the general explanation of pipeline, especially focused on oil and natural gas pipeline, is introduced both in the world and in Japan.

And other kinds of pipeline are also discussed briefly.

1. 1 General Remarks of Pipeline Transportation System

1. 1. 1 History of Pipeline Transportation System

(1) History in the world

The pipeline transportation system is derived from the field of oil industry, because the huge amount of oil could not be transported efficiently by the railroad, which was authorized as the most effective method of massive transportation system of solid objects.

In 1865 the first oil pipeline was constructed from Pitol City, that is a production site of oil, to Millar Farm, that is one of the railroad

stations, in USA.

The pipe was made of cast iron with screw connections in both ends, the diameter and the length of which were two inches and 9.7km, respectively(1).

In those days, the railroad transportation was considered to be more economical and reliable than the pipeline transportation, mainly because the owners of the railroad were in authority of all the fields of transportation.

Sometimes they obstructed the construction of pipeline. In 1874 the first long-distance pipeline from the Northeast Pennsylvania oil field to Pittsburgh was completed after about ten years construction periods against the obstacle of railroad companies.

The diameter and the length of the pipeline were three inches and 96.7km, respectively.

As the amount of oil production increased rapidly, however, the necessity of pipeline transportation grew larger and larger, at the same time the railroad companies could not help accepting the superior characteristics of pipeline.

And in 1879 Tide Water Pipeline between Collybell and Williams Port was completed with the financial support of a railroad company which used to be against the pipeline transportation. The diameter and the length of the pipeline were six inches and 177km, respectively.

Like this, pipeline transportation system penetrated into the field of oil transportation in USA.

As the result of rational modernized decision, oil pipeline transportation expanded rapidly all over the world, especially in Russia, Persia, Iran, Iraq and other countries.

In the field of natural gas pipeline, the development was also achieved in USA as the natural extension of the oil pipeline.

In 1885 the first long-distance natural gas pipeline was constructed from Karn in Pennsylvania to Buffalo.

The pipe was also made of cast iron with screw connections in both ends, the diameter and the length of which were eight inches and 140km, respectively.

The expansion of natural gas and its pipeline transportation was very fast, and in 1900 this system spreaded in seventeen states of fortyeight in USA.

But natural gas pipeline and supply system was operated individually in each local area without any reliable and economical pipeline construction material and devices, especially in the field of pipe material.

After the seamless pipe and ERW pipe was developed as the reliable material pipe in about 1925, huge natural gas pipeline spreaded rapidly in wide area, which is so called "Crass-Country Pipeline" nowadays.

Such a long-distance pipeline is called "Trunk Line" with high pressure, which spreads like a trunk of trees.

And "Distribution Line" with lower pressure is also constructed from its decompression valve stations in order to supply natural gas to consumer areas.

At the end of twenty centuries the total length of trunk pipeline has gotten over 400, 000km in USA(2).

(2) History in Japan

In 1879 the first oil pipeline was constructed in Niigata, the diameter and the length of which were two inches and 2.1km, respectively. The start timing of oil pipeline was not so late compared with that in USA.

And as same as that in USA, pipeline transportation was suffocated by railroad transportation. Under different periodical and geological situation, however, pipeline transportation have not grown in Japan.

That is partly because railroad transportation was to be considered the most important infrastructure to make Japan modernized.

There happened a great event in 1972, when oil pipeline to Narita International Airport was to be constructed.

As the construction of airport itself was not accepted by the whole people, the oil pipeline was also objected and interrupted violently.

In 1983 the oil pipeline from Chiba Port to Narita Airport, the total length of which was 46.7km, was completed at last after ten years from the beginning of construction. In a sense, this pipeline might be a sole oil trunk pipeline, because after this oil pipeline no other pipeline has been laid except in industrial complex districts.

In the field of natural gas pipeline, the first long-distance pipeline was completed from Niigata natural gas field to Tokyo in 1962, the total length of which was 330 km(3).

As the transportation of natural gas is more suitable for pipeline than that of oil, natural gas pipeline has been laid more than oil pipeline so far in Japan.

However, the construction didn't increase because of the surrounding conditions in Japan as follows.

- Construction cost was so expensive.
- Local distribution system was dominant.
- LNG transportation system was superior.
- Social regulation was not relaxed.
- Natural gas was not so expected as an excellent energy.

Table 1-1 shows the existing natural gas pipeline in Japan(4).

It is classified into four categories according to its design pressure, that is, High-Pressure(over 1.0 MPa), Middle-Pressure A(0.3 MPa~1.0 MPa), Middle-Pressure B(0.1 MPa~0.3 MPa), and Low-Pressure (under 0.1 MPa).

About 99% of the total length is possessed by private gas companies because the Low-Pressure pipeline mainly laid to supply to private houses is major in length.

On the other hand, the possessors of the High-Pressure pipeline are divided into two big groups, private gas companies and home gas producers such as Japan Petroleum Exploration Company(JAPEX) and Teikoku Oil Company.

The total length of High-Pressure Pipeline is only three thousand kilometers at most, which is too short compared with that in other advanced countries as shown in Fig. 1-1.

Table1-1 Length of Natural Gas Pipeline in Japan (km)

	Name	HP	MPA	MPB	LP	Total
Private Gas Company	Tokyo Gas	551	2,033	3,537	40,913	47,034
	Osaka Gas	494	1,449	4,126	36,940	43,009
	Toho Gas	117	732	1,715	15,889	18,453
	Saibu Gas	65	443	446	7,429	8,383
	Others	170	6,632	6,050	82,846	95,698
	Total	1,397	11,289	15,874	184,017	212,577
Home Production Company	JAPEX	641		20	30	681
	Teikoku Oil	779		125	20	924
	Total	1,420		145	50	1,615
Electric Company	Tokyo Electric	120		33	0	153
	Chubu Electric	40		25	0	65
	Osaka Electric	26		0	0	26
	Total	186		58	0	244
Others	Total	74		545	153	772
Total		3,077		27,911	184,220	215,208

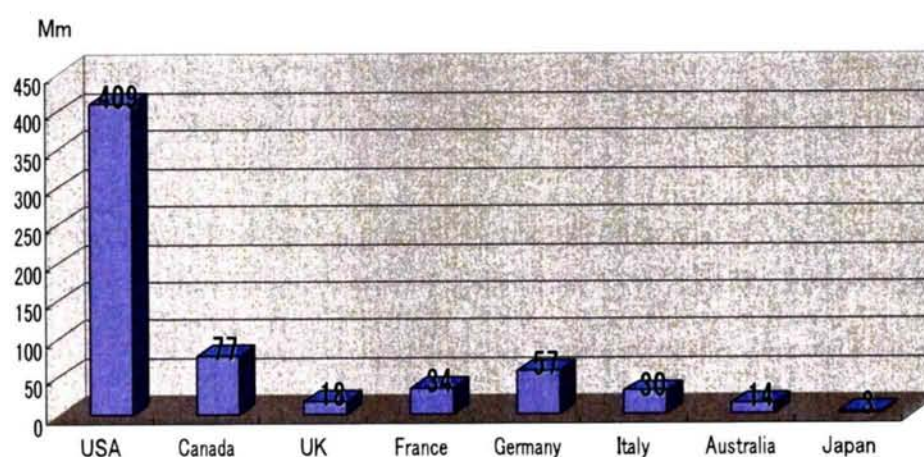


Fig. 1-1 Total Length of HP Pipeline in the world

Recently natural gas has been regarded as a typical clean energy, therefore, the usage amount of natural gas is getting more and more for the purpose of environmental conservation.

Fig. 1-2 shows the usage amount of natural gas recently.

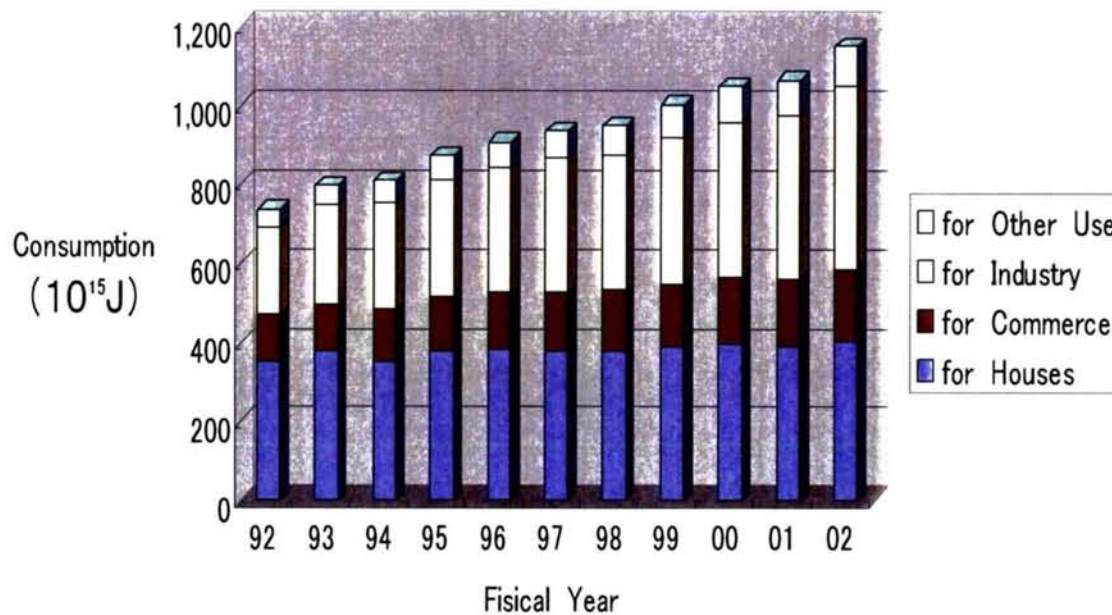


Fig. 1-2 Usage Amount of natural gas(5)

As a result of matter there have been arising a lot of natural gas pipeline plans actively according to the increase of its usage.

1. 1. 2 Present Technical Situation of Pipeline

The present technical situation of various pipeline in Japan has been discussed individually, especially focused on the pipe material which is the most fundamental designing factor of pipeline.

(1) Natural Gas Pipeline

The natural gas pipeline design code has been established by The Japan Gas Association(JGA).

And an aspect of special mention is its aseismic technical efforts after Hansin-Awaji Earthquake.

It might be no exaggeration to say that the material of HP natural gas pipeline is determined by the design code based on aseismic behavior and safety.

Table1-2 shows the fundamental way of thinking against earthquake for each design pressure pipeline.

After plenty of technical reseaches and actual results, the most adequate material and the way of connection was determined as shown in Table1-3.

Table1-2 Fundamental Policy Against Earthquake(6)(7)

Design Pressure	Fundamental Policy
HP(over 1. 0MPa)	<ul style="list-style-type: none"> •No damage, no repair against Level I Earthquake (Occurrence probability is once or twice in life) •Some deformation acceptable, no leakage for Level II Earthquake (Occurrence probability is seldom, but very strong such as inland-type earthquake and ocean trench-type earthquake)
MPA(0. 3~1. 0MPa)	<ul style="list-style-type: none"> •Decrease damages by making pipeline flexible enough •Pipeline should endure against five cm ground deformation except in liquefaction area
MPB(0. 1~0. 3MPa)	
LP(under 0. 1MPa)	

Table1-3 Materials for Each Design Pressure

Design Pressure	Materials(Connection)
HP(over 1. 0MPa)	Steel Pipe (Welding)
MPA(0. 3~1. 0MPa)	Steel Pipe (Welding) for liquefaction area Ductile Pipe (Mechanical) for other area
MPB(0. 1~0. 3MPa)	Ductile Pipe (Mechanical)
LP(under 0. 1MPa)	Polyethylene Pipe (Fusion) for underground Steel Pipe (Screw) for overground

The steel pipe code and grade usually adopted and admitted by the Gas Utility Industry Law is listed in Table1-4.

Table1-4 Steel Pipe Code and Grade for Each Design Pressure

Design Pressure Level	Code	Grade	Minimum Tensile Strength	Other Requested Properties
High (HP)	American Petroleum Institute (API 5L)	X42	414MPa	(usually) Brittleness
		X52	455MPa	
		X60	517MPa	
		X65	531MPa	
Middle(MP)	Japan Industrial Standard (JIS)	SGP	290N/mm ²	
		STPG370/STPT370	370N/mm ²	
		STPG410/STPT410	410N/mm ²	
		STPY400	400N/mm ²	
Low (LP)	JIS	SGP	290N/mm ²	

For Middle-Pressure and Low-Pressure natural gas pipeline, the Japan industrial standard (JIS) is applied as a matter of course. Especially for High-Pressure pipeline which is requested maximum safety level, the API Standard has been applied based on its reasonable technical requirements and numerous previous results in the world.

Because pipeline is usually laid underground, it must be executed outer coating for the purpose of corrosion protection.

Although it is common that the corrosion protection tape is executed on the bare pipeline after site welding connection in the foreign countries, the factory polyethylene outer coating of pipe is usual in Japan, the code of which has been also provided in JIS.

(2) Oil Pipeline

Fundamental technical requirements for oil pipeline are decided in “Oil Pipeline Technical Standard”, which is the origin of natural gas pipeline design code.

As almost all of the oil pipeline projects except for Narita Pipeline are limited within industrial complex districts, the technical arrangement is behind gas pipeline nowadays.

The adequate material of oil pipeline, however, could be thought as the same as natural gas pipeline, because the required characteristics are almost the same.

In Japan not crude oil but processed oil such as jet engine fuel is usually transported, therefore, the inner condition of pipeline must be noticed carefully.

(3) Water Pipeline

Water pipeline has been spreaded so extensively and widely that the coverage of waterworks is over 96% in Japan.

Therefore, the main technical theme is getting not to construct new facilities but to raise the quality of water and to renew existing facilities.

The fundamental technical requirements are determined in “Water Facility Design Code(2000)”, and the items concerning materials are summarized as below.

- i) To endure against long-time usage
- ii) Not to affect water quality
- iii) To be easy in maintenance
- iv) To be adequate to its surrounding conditions

And in consideration of construction cost, pipe materials are usually selected as Table1-5.

Table1-5 Pipe Materials for Water Pipeline

Laying Condition	Pipe Daimeter	Material (Connection)	Decisive Factor
Under Ground	Under 900A	Ductile Pipe (Mechancal)	Laying Cost
	Over 900A	Steel Pipe (Welding)	Laying Cost
Over Ground	ALL	Stainless Pipe (Welding)	Maintenance

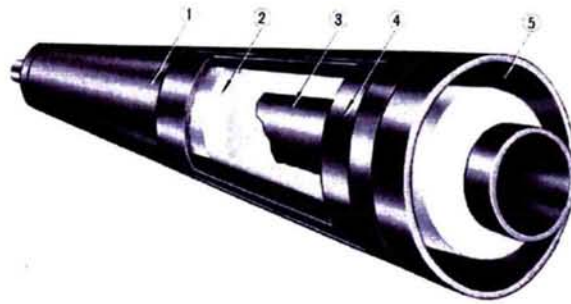
(4) Steam and Hot Water Pipeline

In case of District Heating & Cooling systems(DHC) and the energy discharged systems, steam and hot water pipeline is necessary. This trend of heat energy application is increasing against the background of energy saving, and as a result, steam and hot water pipeline is expected to increase more.

In order to construct steam and hot water pipeline, we must insulate mother pipe using insulator, and more over must isolate mother pipe from surrounding structure such as earth in case of buried pipeline. Therefore, double-pipe system is usually adopted, which consists of mother pipe, insulator, and casing pipe.

Because the strength against the heavy weight and the elongation ability is required, steel pipe is usually selected both as mother pipe and casing pipe.

Fig. 1-3 shows typical double-pipe system used in DHC.



①Outer Coating ②Insulator ③Mother Pipe ④ Casing Pipe ⑤ Air Insulator

Fig. 1-3 Typical Double-Pipe System

(5) Liquefied Natural Gas Pipeline

We have about twenty Liquefied Natural Gas(LNG) terminals in Japan, which are the original points of natural gas pipeline.

LNG pipeline was laid from the berth to the NG vaporizer in every terminal.

The temperature of LNG is so low(-162°C) that the sufficient mechanical property in low temperature region is required for pipe material. And in addition, anti-shrinkage devices such as pipe loops must be considered by heat stress analysis.

Usually stainless steel pipe is selected, but heat absorption pipe loops or expansion joints must be placed in relatively short intervals.

Recently Invar Alloy Pipeline System has been already established, which enables no loop piping as shown in Fig. 1-4.

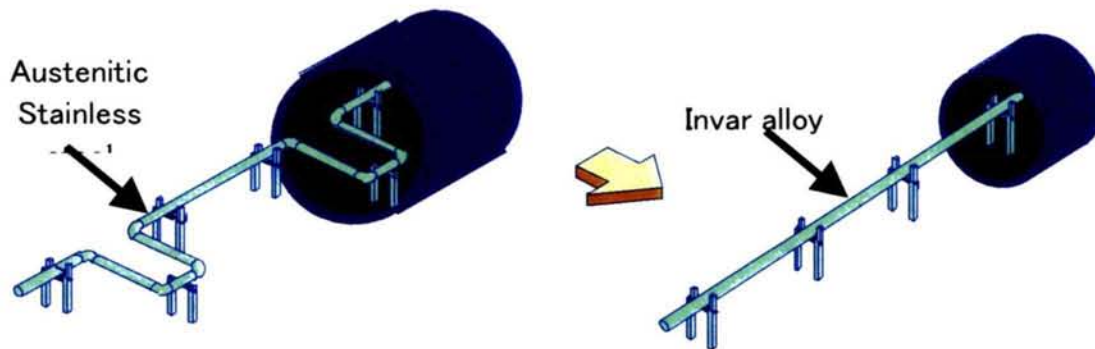


Fig. 1-4 Loopless Invar Alloy LNG Piping

(6) Solid Transportation Pipeline

Solid articles can be also transported as efficiently as natural gas and liquid using pipeline. The typical examples are slurry pipeline system and capsule pipeline system.

The former system is soil (or others) and water mixed transportation so-called "Solid-Liquid Two-Phase Flow", where the wear of pipe is one of the biggest technical theme in usage.

The pipeline of latter system is like the railroad, in which wheeled capsule trains run through shown in Fig. 1-5.

Pipeline must be designed to endure the weight of capsule trains.



Fig. 1-5 Capsule Pipeline with Capsule Trains

Capsule Pipeline Transportation System is a revolutionary system for multipurpose mass transportation, the capsule trains of which run in the pipeline at regular intervals.

The total system, including the velocity control of capsule trains, is fully controlled by the computer system making the transportation safe and reliable.

The features of this system are summarized as follows.

- Clean, safe and no adverse impact on the environment
- Ideal for continuous mass transportation
- Acceptable to many load types and various situations
- Independent of weather
- Maintenance free of pipeline
- Extremely high labor productivity

The comparison of Capsule Pipeline Transportation System with other transportation systems is summarized in Table1-6.

Table1-6 Comparison of Solid Article Transportation Systems

	Capsule	Truck	Conveyer
Velocity	30~40km/H	20~100km/H	5~20km/H
Punctuality	Good	Traffic Conditions	Good
Route	Pipeline	Road	Conveyer
Vehicle	Car	Truck	None
Power	Central Power	Individual Power	Several Sources
Automation	Central Control	Manual Operation	Central Control
Maintenance	Easy	Easy	Difficult
Operator	Few	many	Few
Safety	Safe, Sanitary	Traffic Accident	Spillage
Pollution	Minimum	Air, Noise	Noise
Others	Initial Investment	Traffic Accident	None

1. 2 Change of Surrounding Social Conditions

(1) Liberalization of Energy Markets

It has been said that the consumer prices of both electricity and natural gas are too expensive as compared with those in foreign countries.

Fig. 1-6 shows international prices of electricity, and Fig. 1-7 shows those of natural gas, respectively.

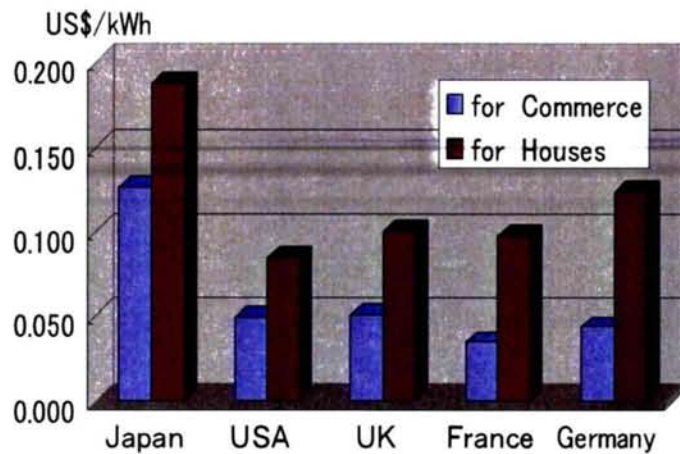


Fig. 1-6 International Comparison of Electricity Price(8)

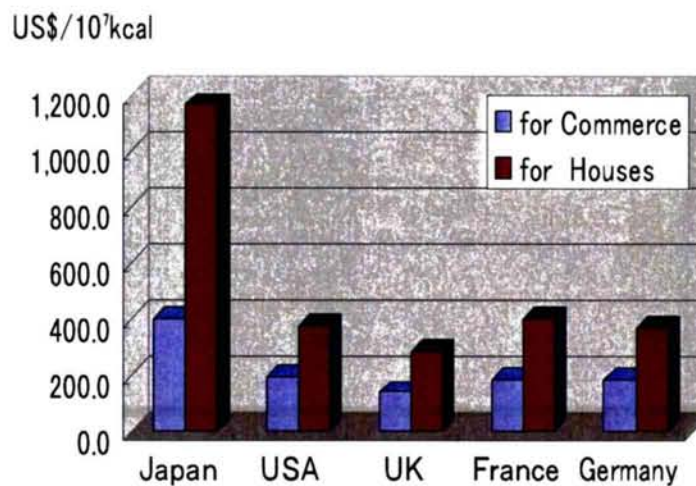


Fig. 1-7 International Comparison of Natural Gas Price(9)

From the figures above we could come to the conclusion on prices of electricity and natural gas as follows.

<Electricity>

- The Japanese prices both for commerce and houses are about from twice to three times those of USA, UK, France and Germany.

<Natural gas>

- The Japanese price for commerce is about twice that of USA, UK, France and Germany.
- The Japanese price for houses is about from three to five times that of USA, UK, France and Germany.

And it might be only natural that the people request to correct the excessive differences by the efforts of the servicers and the nation.

Under these surrounding conditions, the Ministry of Economy, Trade and Industry(METI) has been liberalizing the market of electricity and natural gas rapidly in last decade.

As one of the greatest results, electricity and natural gas that had been monopolized by the local electricity companies and gas companies has been getting liberalized as shown in Table1-7.

Table1-7 Liberalization of Electricity and Natural Gas

Fiscal Year	Electricity	Gas
1995	IPP Start	over 2,000,000m ³
1999	over 2,000kW	over 1,000,000m ³
2004	over 500kW	over 500,000m ³
2007	All Customers	over 100,000m ³
undecided	—	All Customers

This national trend makes the energy market so activated that new streams of natural gas transportation are going to appear.

(2) Environmental Protection

In 1997 Kyoto Protocol adopted the output amounts of Greenhouse Gases(GHGs) in advanced countries should be controled under acceptable target values.

Among the defined six GHGs, which are CO₂, CH₄, N₂O, HFCs, PFCs and SF₆, CO₂ makes up ninety percent of all in Japan as shown in Fig. 1-8.

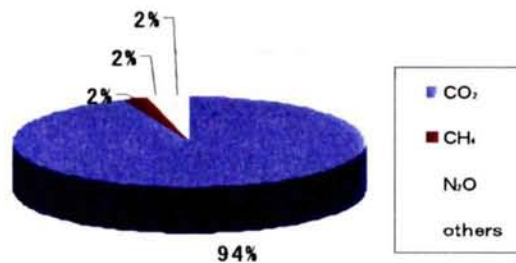


Fig. 1-8 Gas Proportion of GHGs(10)

As a result of human economical activities, CO₂ is generated in various field. Fig. 1-9 shows CO₂ generation field proportion.

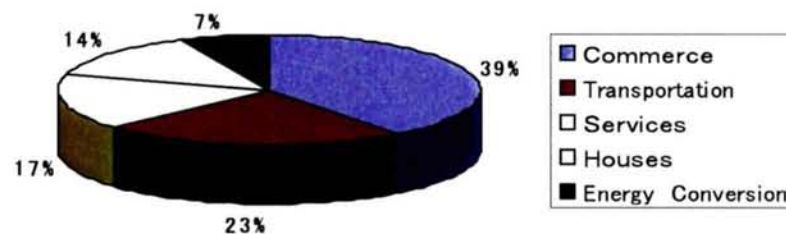


Fig. 1-9 CO₂ Generation Field Proportion(10)

According to this protocol we must realize the output amount of CO₂ in 2010 shall keep under the same level as that in 1990.

In order to achieve this purpose the concrete measures as below must be done.

- ① To save energy in every field
- ② To decrease energy loss using Co-Generation System
- ③ To change to clean energy that accompanies less CO₂

Not only in thermal power generations but also in the commerce and in the houses, natural gas is already authorized as a superior energy because it generates less CO₂ than coal by 40 percent, and than oil by 25 percent.

In those reasons the concrete measures ② and ③ hereafter will make the usage amount of natural gas greater and greater.

(3) Promotion of IGF21

In 1990 the Ministry of International Trade and Industry(MITI) proposed to all the gas servicers that the domestic gas should be integrated into high calorie gas until 2010, which is so called "Integrated Gas Family21(IGF21)".

The purposes of this proposal are popularization of natural gas, enlargement of customers' convenience, and intensification of energy supply foundations through long-range cost down, from the viewpoint of gas servicers' modernization and customers' service improvement.

The practice of this reformation, however, costs so much that the gas servicers can not help opening up new customers, because they can not shift the cost onto the customers.

(4) Deregulation of the Gas Utility Industry Law

For the purpose of accelerating liberalization of natural gas, the Gas Utility Industry Law was revised in 2004.

The main revised points are as follows.

i) Arrangement of efficient natural gas supply foundations and promotion of their effective use

① Starting of natural gas pipeline business

Gas Pipeline business has been newly placed in the Gas Utility Industry Law in order to arrange the public privileges in case of pipeline construction for any competitor.

② Enlargement of natural gas consignment system

Natural gas consignment which was obligated to only big four gas companies (Tokyo Gas, Osaka Gas, Toho Gas, and Saibu Gas) has been enlarged to all the gas servicers.

ii) Enlargement of the customers' supplier choice

③ Review of regulation for big order customers

The permission rule in force for big order customers has been changed into the notification rule from the viewpoint of urging the suppliers to make efficient efforts.

④ Abolition of natural gas wholesale regulation

The wholesale regulation in force has been abolished from the viewpoint of promoting free competitions in customers' procurement of natural gas.

iii) Adoption of the notification rules for the other procedures

The regulations and rules in case of gas facility modifications and particular gas supplication have been also changed from the permission rule in force to the notification rule.

These trends toward reregulation of the Gas Utility Industry Law will makes natural gas pipeline transportations more active in both quantity and quality.

(5) Needs for Onsite Power Plants

It has been already recongnized that the co-generation system (CGS) is one of the most effective energy systems, therefore, the reseach and development of CGS has been executed energetically and continuously.

The reason why CGS is considered as an excellent energy system is its high thermal efficiency in case of onsite power plants.

Even in the latest compound cycle thermal power generation, the thermal efficiency is only 40% at most, moreover transmission loss of electricity can not be negligible.

On the other hand, in case of CGS used as an onsite power plant, 80% of thermal efficiency has been attained by the Thermal Cascade Utilization, in which thermal energy is utilized efficiently from high temperature stage to the lower temperature stages respectively like a cascade.

Thus CGS has been incresing as an energy saving and environment protecting system as shouwn in Fig1-10.

The cumulated total electric power by CGS amounts to more than sixty million kW in 2001.

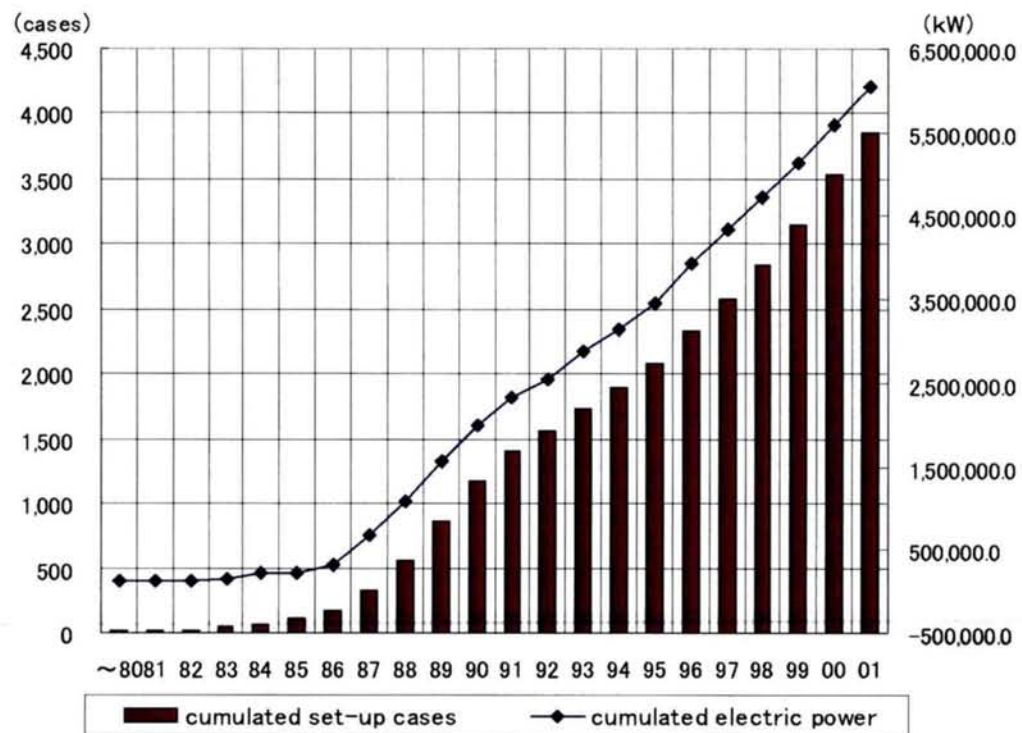


Fig. 1-10 Increase of CGS Plants(11)

1. 1. 3 Objectives and Scopes

The purpose of this study is to develop and spread pipeline transportation systems, especially in Japan where the progress of pipeline is obviously inferior to other advanced countries.

The immaturity of pipeline arrangement might be one of the greatest weak points in the further development of Japan, which has been the anxious concern for the author who has been engaged in pipeline engineering for 25 years.

Recently the surrounding conditions of energy fields has been especially changing rapidly against the background of environmental protection problem.

The deregulation of the domestic energy and pipeline law has been also stepped up rapidly in order to adapt to further globalization.

Under such circumstances, the author has made a comprehensive compilation on the pipeline technology, almost of which has been prepared to practical use.

As explained in this chapter, the technology of pipeline has already developed so far, however, further development is necessary to keep and raise the quality and achieve the economical services for the customers and consumers.

In Chapter 2, the development of natural gas pipeline construction systems is summarized, which will provide high-quality natural gas pipeline with economical costs.

The successful results of each system will be useful for further national pipeline projects in the future.

In Chapter 3, the feasibility study of high-pressure direct supply system is introduced, which may be profitable for mass transportation of natural gas such as on-site CGS plants in the future.

In Chapter 4, the new technology using inner alloy pipe which enables LNG pipeline and piping more simple and economical is summarized. There increasing LNG terminals not only in Japan but also in the foreign countries, this development has been watched in keen interest in the world.

In Chapter 5, the heat transportation pipeline system developed for hot water is introduced. The results of development has been ascertained and presented for practical use in the USJ DHC system.

In Chapter 6, the development of pipeline maintenance technology is introduced, which enables non-destructive inspection and testing of existing pipeline. The needs for these maintenance is increasing day by day, and the further trial might be necessary.

Chapter 7 shows the several conclusions that can be drawn from this study.

Chapter 2 Development of Natural Gas Pipeline Construction Systems

For the purpose of both speed up in progress and lowering in cost, modernized automatic construction systems have been developed especially in the field of high-pressure long distance pipeline.

Automatic construction systems of pipeline are composed of these systems as follows.

- (1) Automatic Welding System
- (2) Automatic Ultrasonic Inspection System
- (3) Automatic Site Coating System
- (4) Economical Non-Dig Construction System
- (5) Combination of Each System

2. 1 Automatic Welding System

(1) Welding Process

In the manual welding procedure, shield metal arc welding(SMAW) with multilayer is usually used for the first layer of welding called the “Root Pass”, for the upper layers called the “Filler Pass”, and for the last layer called “Cap Pass”.

Gas tungsten arc welding(GTAW) is sometimes adopted for the Root Pass owing to the difficulty of penetrating welding.

In case of high tensile strength pipe, low-hydrogen electrodes must be used to reduce the diffusible hydrogen which damages the ductility of material.

Because almost all the portions of pipeline are underground, the working circumstances of welders might not be so enough to achieve high-quality girth welding. That might be one reason why automatic welding systems are necessary especially for large-diameter and thick-wall pipeline.

The other hand in case of automatic welding procedure, gas metal arc welding(GMAW) with mixed shielding gas is usually adopted among considerable welding factors as follows.

Table2-1 Factors of Automatic Welding Process

Automatic Welding	Shielding Gas	Wire	Electrode
	1. Active Gas ① CO ₂ ② CO ₂ + Ar	1. No-Flux	1. Tungsten
	2. Non-Active Gas ① Ar	2. With Flux	2. Metal

Selecting the factors above, the automatic welding machine which is the heart of the total system has been developed keeping pace with the development of computer control and sensor devices.

In the initial stage of automization the degrees of the groove was the same as the manual welding procedure(60 degrees), and the torch of arch head was only one.

Therefore, advanced automatic welding systems have been developed in order to supply the best system for various site conditions.

(2) Advanced Automatic Welding Systems

Table2-2 shows four types of the advanced automatic welding systems in case of high-pressure pipeline with large diameter from 600A to 750A, with the laying conditions and welding rate.

Table2-2 Advanced Automatic Welding Systems(12)

Laying Conditions	Laying Underground (Much affected by earth works)		Laying into Shield Tunnel etc. (Less affected by earth works)	
Welding Rate	1	2	3	4 (Rings/day)
High-Pressure Pipeline (600A ~750A)	①Narrow Gap 1-Head MAG Automatic Welding System ② Narrow Gap 2-Head MAG Automatic Welding System			
			③Both-Side 3-Head MAG Automatic Welding System ④Spread MAG Automatic Welding System	

① Narrow Gap 1-Head MAG Automatic Welding System

This system is designed for application to the general underground works where the progress of earth works will affect the efficiency of piping works as a whole.

In other words, the total efficiency is controlled by earth works rather than the piping works because the excavating and backfilling ability restricts the total progress.

As the welding rate is 1~2 Rings a day at most, complicated welding systems are not necessary.

The groove angle for V butt weld is narrowed from the conventional 60 degrees to 40 degrees, which makes it possible to decrease the deposit cross-sectional area to approximately 70%, which enables great

reduction in the arc time.

In case of the diameter and the wall-thickness are 750A and 19mm respectively, the arc time of the conventional welding (1-Head : 60 degree V-groove) is 180 minutes, whereas the time of developed narrow gap 1-Head MAG automatic welding is 110 minutes.

② Narrow Gap 2-Head MAG Automatic Welding System

The fundamental technology of this system is based on 1-Head MAG. For the purpose of the arc time reduction, one more torch of arc head is added with multihead control devices.

In case of the diameter and the wall-thickness are 750A and 19mm respectively, the arc time of 2-Head MAG Automatic Welding Machine gets only 70 minutes.

The outline of 2-Head MAG Automatic Welding Machine is shown in Fig. 2-1.



Fig. 2-1 Outline of 2-Head MAG Automatic Welding Machine

③ Both-Side 3-Head MAG Automatic Welding System

This system is developed for the site conditions of shield tunnels and similar conditions where only the welding rate will affect efficiency of piping work with no influence on earth works.

Therefore new technologies have been developed as follows to achieve the welding rate of more than 2 Rings a day .

- Adoption of X-groove
- In-Process Monitored 2-Head Welding Device
- Internal Clamp and Welding Device

<Adoption of X-groove>

Adopting X-groove which makes the deposit area less than V-groove, the both-side welding can be performed to shorten the arc time. And in order to stabilize the welding quality of the both side welding, “In-Process External 2-Head Welding Device” and “Internal Clamp and Welding Device” have been developed.

<In-Process Monitored External 2-Head Welding Device>

The welding line tracking has been measured previously before girth weld in conventional system, on the contrary In-Process Monitoring during all the process of welding has been developed by using optical sensors and quick computer control system, which has enabled stable multilayer welding of thick wall pipe and manipulation of multiple heads by a single operator.

In order to shorten the time for installing and dismantling the device, and to minimize the interference between the two heads, the weight and dimensions of welding heads and guide rails have been reduced to approximately half of the previous devices.

The outline of the developed device in comparison with the previous device is shown in Table2-3.

Table2-3 In-Process External 2-Head MAG Automatic Welding System

Item		In-Process External 2-Head MAG	Previous Automatic MAG
Controller	Number of heads	2-head	1-head
	Mode	Adaptive control	Teaching play back
	Tracking of weld line	In-process sensing (Optical sensor)	In advance (Contact sensor)
	Input of welding conditions	By off line device	By off line device
Welding head		2-head/rail	1-head/rail
Rail	Traveling	Rack and pinion	Rack and pinion
	Setting	One touch	Fastening by bolts

<Internal Clamp and Welding Device>

In the conventional single-V butt joint penetration welding, alignment and clamping (fixing the ends of both the installed pipes and the pipe to be installed) used to be performed by screw type inner clamp.

This work was performed manually from inside of the pipe, however, it took much working time under severe circumstances.

Furthermore, the precision of laying the copper backing strip may affect the welding quality a great deal.

To remove this limitation, this device with both hydraulic clamping and internal welding function has been newly developed, thus penetration welding has been replaced by both-side welding (double-V butt joint) method, which has contributed to quality stabilization and substantially shortening of the alignment time.

The outline and specifications of the device are shown in Fig. 2-2, Fig. 2-3 and Table2-4, respectively.

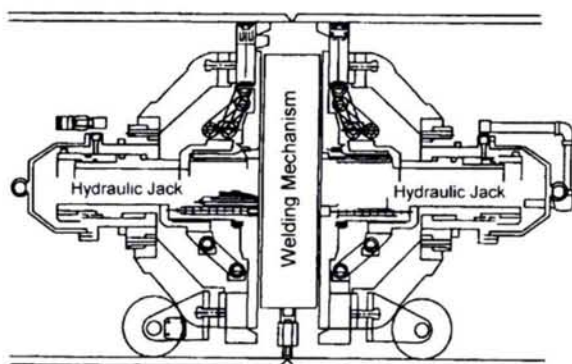


Fig. 2-3 Hydraulic Clamping Device



Fig. 2-4 HCD in pipe

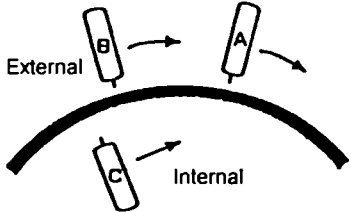
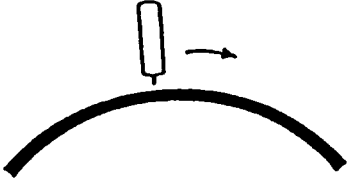
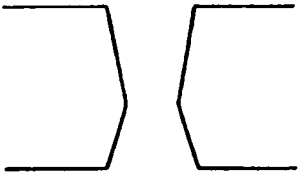
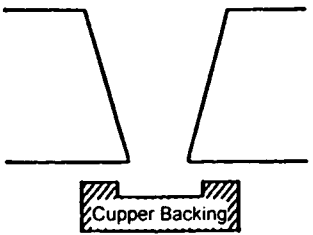
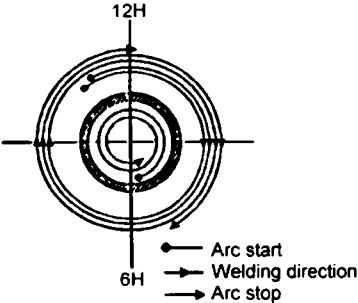
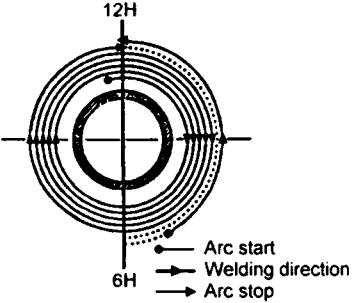
Table2-4 Specification of Internal clamp and Welding Device

Item		Specification
Controller	Control mode	Teaching play back
	Tracking of weld line	In-process tracking (Eddy current sensor)
Welding head	No. of torches	1
	Wire feeding velocity (m/min)	1~15 (ϕ 0.9mm Solid wire)
	Traveling velocity (cm/min)	0~50 (Rotating range ± 370 degree)
	Operating range	Axial direction of pipe (Weaving direction) 30
Wall thickness of pipe (Vertical direction) 40		
Welding power		Constant voltage characteristic
Shield gas		Mixed gas (Ar + CO ₂)
Pipe to be applied		For 750A
Clamp		Hydraulic inner clamp (Clamp force: 5 ton/claw)

<Comparison between Narrow Gap Automatic MAG Welding System
and Both-Side Automatic MAG Welding System>

The comparison between the both systems is shown in Table2-5.

Table2-5 Comparison of the both systems

	Both-Side Automatic MAG	Narrow Gap Automatic MAG
Number of Torches	3 Torches (External 2 + Internal 1) 	1 Torches 
Groove Geometry		
Build-up Sequence		
Welding Time	20%	100%

Narrow Gap Automatic MAG Welding System has shortened the welding time to 70% compared with the previous system by reducing the deposit cross-sectional area ($60^\circ V \rightarrow 40^\circ V$: approximately 70%), meanwhile the both-side automatic MAG welding method has enabled reduction of the welding time by approximately 20% compared with

the previous method, which is achievable by way of increasing the torch numbers (1→3 torches) and by decreasing the groove cross-sectional area.

In case of pipe with 762mm diameter and 19mm wall thickness (API-5L-X65), the arc time of respective welding torch has been reduced to about 30 minutes by optimizing groove geometry.

Consequently this arc time reduction has also shortened the welding time by nullifying the welding arc interruption previously required for nozzle cleaning during welding.

As the result, the welding time has been accomplished within about 35 minutes from the arc start of internal head to the external welding completion.

④Application of Both-Side 3-Head MAG Automatic Welding System

<The application situation>

The practical usage of this system started in June 1998 after having acquired the approval of the welding procedure specification in accordance with the Gas Utility Industrial Law.

As the passing rate of X-ray inspection has been assured to be almost 100%, stabilized high quality welding has been demonstrated in the field application.

Fig. 2-5 shows the on-site welding performance of this system.



Fig. 2-5 Application of Both-Side 3-Head MAG Welding System

<Welding efficiency>

As in case of narrow surrounding condition such as shield tunnels, the next welding process must be started one by one after the whole process of the former ring has been completed. Therefore, the parallel works of welding and inspection are not feasible. For this reason, the welding rate is usually only 1 Ring a day by the previous system.

The required completion time of welding and inspection for each ring using the previous system used to be about 4.5 hours, however, it has been reduced to 3.2 hours using Both-side 3-Head MAG Automatic Welding System as a result of high-speed welding.

The shortening of working time by more than one hour a ring has enabled efficient piping process of 2 Rings a day.

⑤ Spread MAG Automatic Welding System

In order to bring out the further advantage of Both-Side 3-Head MAG Automatic Welding System, Spread MAG Automatic Welding System has been developed and executed in the field.

In this system the piping process of welding, inspection and coating can be executed in the respective ring at the same time like “Spread Construction Method” that is well-known as a typical efficient pipeline construction method.

The sequential work shift to the next welding ring is not necessary because stringing and alignment of pipe, welding, inspection and coating works can be started concurrently and independently along pipeline.

In the conventional automatic system, it was difficult to separate the welding operation from pipe stringing and alignment work because an internal backing metal was required in the V-butt joint penetration welding method.

On the other hand, this Both-Side 3-Head MAG Automatic Welding System enables the carrying out of internal welding immediately after completing alignment. Therefore, the timing for external welding is not delayed by application of the backing metal.

With this background, an efficient and fully automatic welding spread system has been developed. The following Fig. 2-6 indicates the outline of Spread MAG Automatic Welding System.

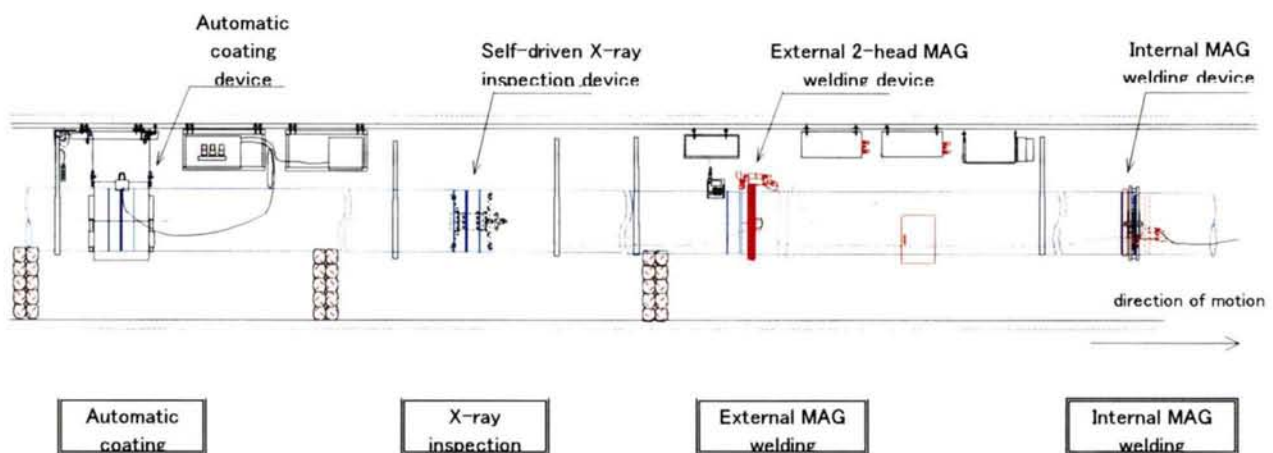


Fig. 2-6 Spread MAG Automatic Welding System

<Outline of the devices>

The individual devices of Spread MAG System are the same as Both-Side 3-Head MAG Automatic Welding System, which consists of an external 2-Head MAG automatic welding device and an internal 1-Head MAG automatic welding device.

There was no need in this system to concurrently carry out the automatical welding for internal and external joints, therefore, it is possible to set up the joint of pipe for line-up alignment from outside of the pipe when internal welding has been carried out.

The method of alignment using a screw type outer clamp has been employed and an internal welding device has been newly developed. In addition, for automating the inspection work, the self-driven X-ray inspection device has been also developed.

The outline of the devices are shown in Fig. 2-7 and Fig. 2-8.



Fig. 2-7 Internal Welding Device



Fig. 2-8 Self-Driven X-Ray

Inspection Device

<Weld Efficiency>

Being different from the previous automatic welding systems, such works as internal welding, external welding, inspection and coating can be carried out in parallel. Thus high efficiency of the whole piping work is feasible.

In case of pipe with 762 mm diameter and 19 mm wall thickness, the welding rate can be easily expected from three to four Rings a day.

⑥ Development of In-Process Control System

Under the conventional fully automatic welding system with weldline tracking using a contact sensor, the entire welding course was made from pre-recorded data.

In addition, since the welding conditions were specified beforehand based on given standard joint geometries, a high of level accuracy of alignment and edge preparation was required.

To cope with this situation, an in-process control method has been developed aiming at promotion of full-automation and stabilization of

weld quality.

This device can scan and detect in real time weld beads and groove shape continuously as the welding work progresses.

Thereby the alteration of welding conditions and subsequent weld line tracking can be followed, which enables the high quality welding equivalent to that produced by manual welding even when groove accuracy is pretty poor.

Fig. 2-9 shows the outline of the development comparing with the conventional operation, and the concept of the in-process control system.

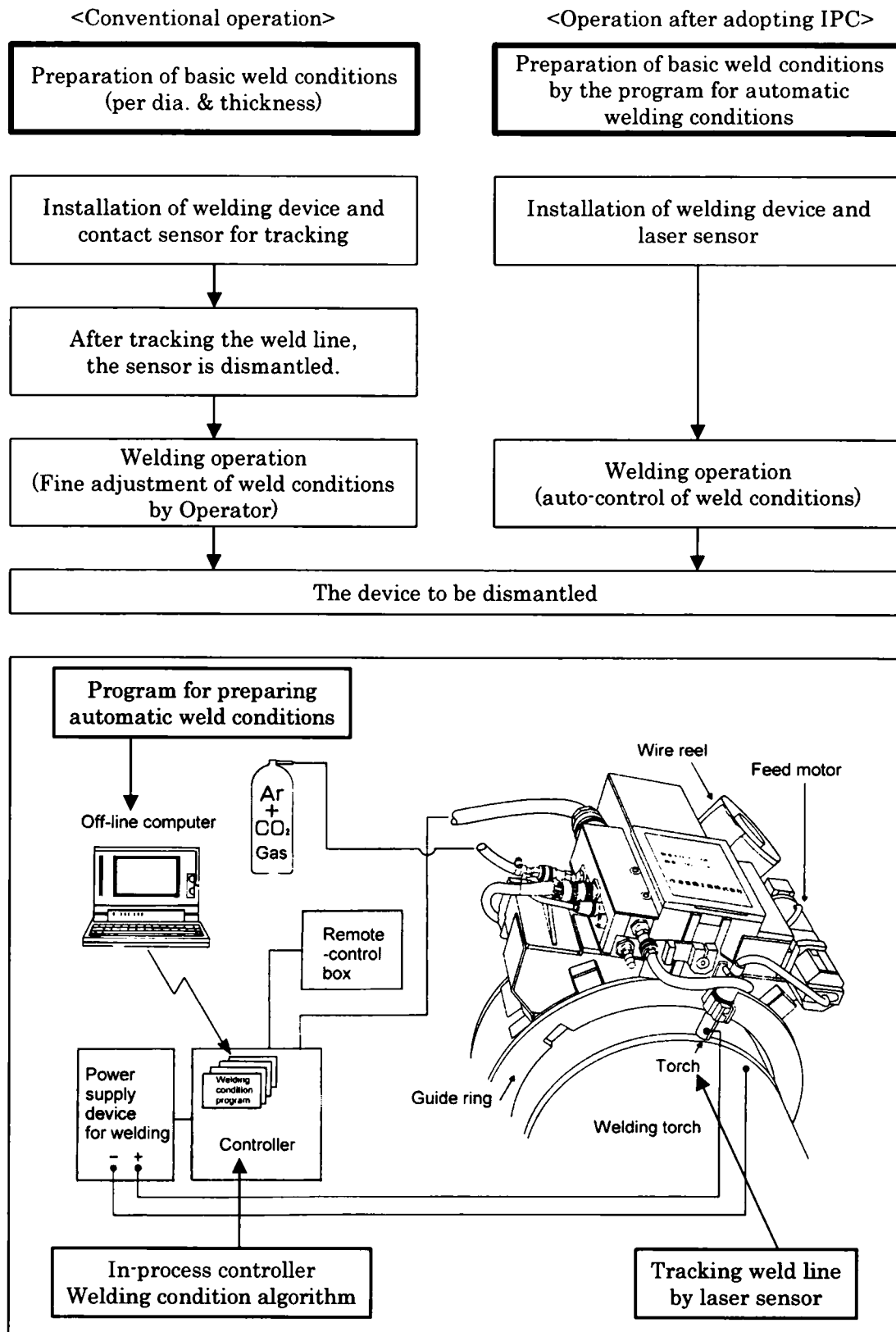


Fig. 2-9 Concept for the development of In-Process Control(IPC)

<Objectives of the development>

- i)Improvement to achieve the high accuracy of groove tracking using laser sensor
- ii)Establishment of in-process weld condition algorithm
- iii)Establishment of in-process control system by combination

<Details of the development and its results>

- i)Improving the detective capability of groove shapes

Since the measures to prevent arc noise affecting the laser sensor have been incorporated in hardware and the optimization for measuring method of groove shapes, the high level accuracy ($\pm 0.2\text{mm}$) and stabilization for detecting groove position and shape has been accomplished, and real time groove tracking has also been achieved.

- ii)Establishment of the weld condition algorithm

Although various adjustment methods of the weld conditions are conceivable, it has been adopted as the basic algorithm that the prescribed standard weld condition should be altered subsequently by following the difference detected from the actual groove shape under welding and the formerly prescribed groove conditions.

Groove shapes are classified in three types (or combined types) as indicated in Fig. 2-10.

Based on a study of adjustment methods for the following three types which are "Root gap difference", "Bevel angle difference" and "Misalignment", the algorithm of welding conditions has been produced.

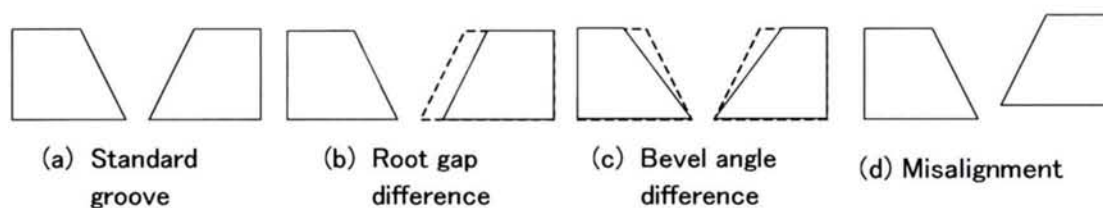
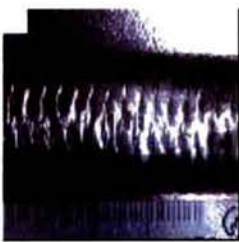




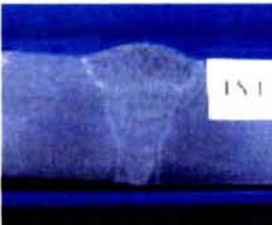


Fig. 2-10 Groove shapes

<Test results of welding using in-process control>

Based on the dispersion range of groove shapes found in the past records of the field automatic welding operations so far, it has been confirmed that the in-process control functioned normally and the good quality has been achieved.

Typical examples of bead appearance and cross sectional macro photographs are shown in Fig. 2-11.

	External bead appearance	Internal bead appearance	Cross sectional macro photo
Standard groove			
Gap 3 mm groove			

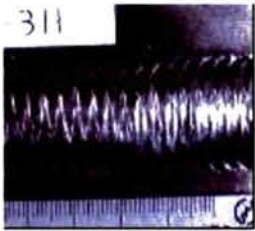



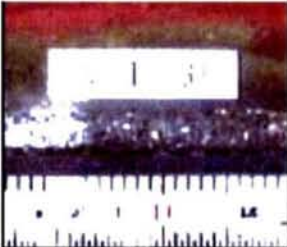
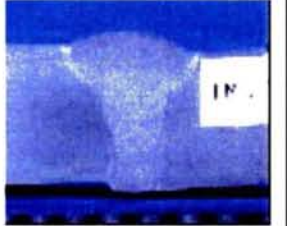


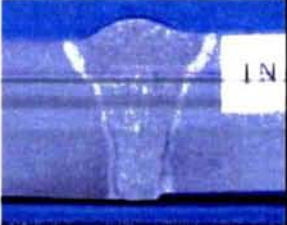


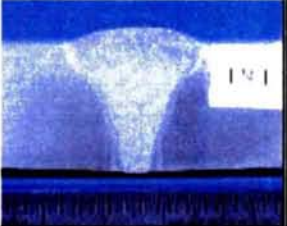
Gap 5 mm groove			
Misalignment			
Narrow-angle groove			
Wide-angle groove			

Fig. 2-11 Test results of welding by using In-Process Control

2. 2 Automatic Ultrasonic Inspection System

In the field of pipeline construction, only the radiographic testing(RT) had been authorized as the legal inspection method, however, on April 1st, 2004 the ultrasonic testing (UT) has newly authorized as an another insepection method in the Gas Utility Industry Low by the Ministry of Economy, Trade and Industry.

Although this revision has been laid down with the seabed pipeline standard which is one of the greatest poblems of urgency in Japan, this revision shall change the entire pipeline construction method because it also makes inspection on land more efficient.

Preceding this revision, a lot of reseaches and developments had been accumulated, where the safety reliablity of UT is assured to be the same as RT(13).

For the purpose of ascertaining the reliability of the UT method called “High-Speed Zigzag Scan UT System”, researches and developments were fully fulfilled as a national project sponsered by JGA for five years, as bescribed below.

(1) The point at issue of RT

RT has been established as a reliable non-destructive inspection way for pipeline construction, and it will be mainly adopted in the field of steel structures from now on, too.

However, especially in the field of pipeline, because of the restraint of the construction space and total working time a day, RT has such points at issue as follows.

- Necessity of facilities not to be bombed
- Judgement takes too much time (approximately 1~2 hours)

In that reason, alternative inspection method has been expected for the purpose of further efficiency of pipeline construction.

(2) The aiming target of the alternative UT

UT has already been accepted as the final inspection method in various fields, and it has been authorized as the final inspection method even in the pipe manufacturing.

Inspection precision itself has no problem, however, it should possess new features as below from the viewpoint of outside field activities in case of 600A~750A pipeline construction.

- ① Speedy inspection less than five minutes a ring
- ② Having performance equal to that of RT
- ③ Being fully automatical including inspection records
- ④ Satisfying the criterion of automatic ultrasonic inspection of girth weld of natural gas pipeline by JGA

(3) Outline of High-Speed Zigzag Scan UT System

① Inspection Devices

This system is composed of three units as shown in Fig. 2-12.

Fig. 2-13 and Fig. 2-14 show the appearances of the whole device and the flaw detection unit, respectively.

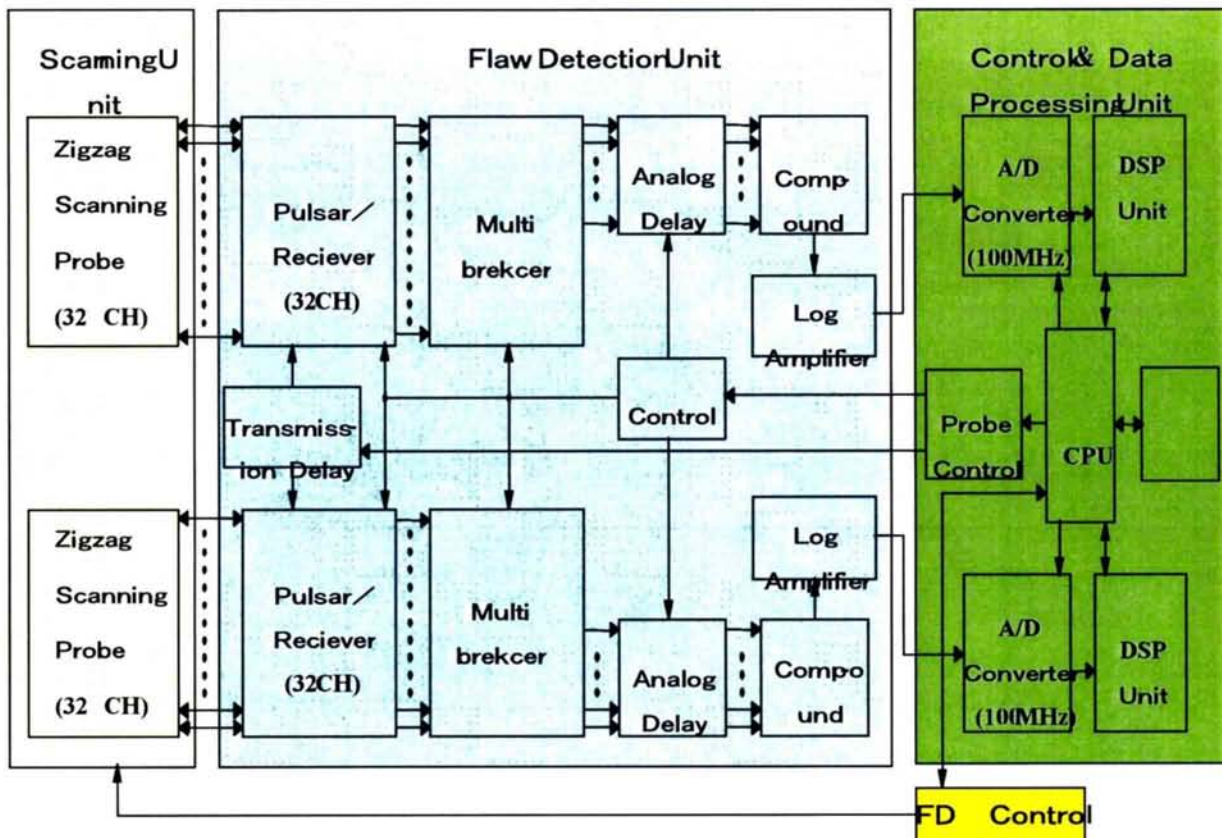


Fig. 2-12 System Block of High-Speed Zigzag Scan UT Device

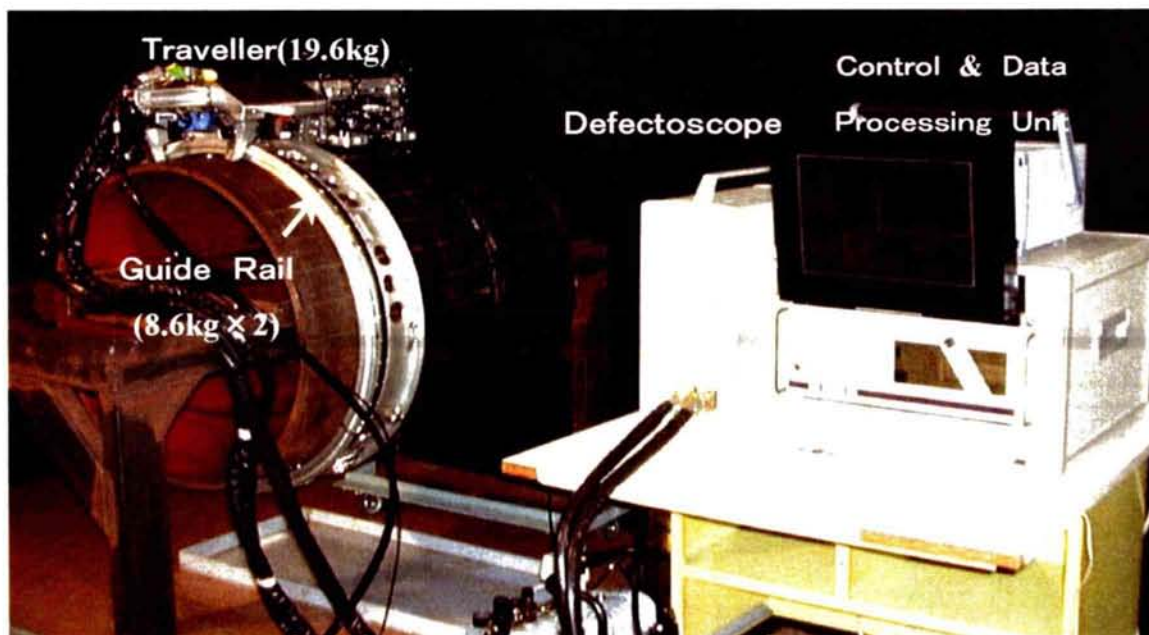


Fig. 2-13 Appearance of the Whole Device

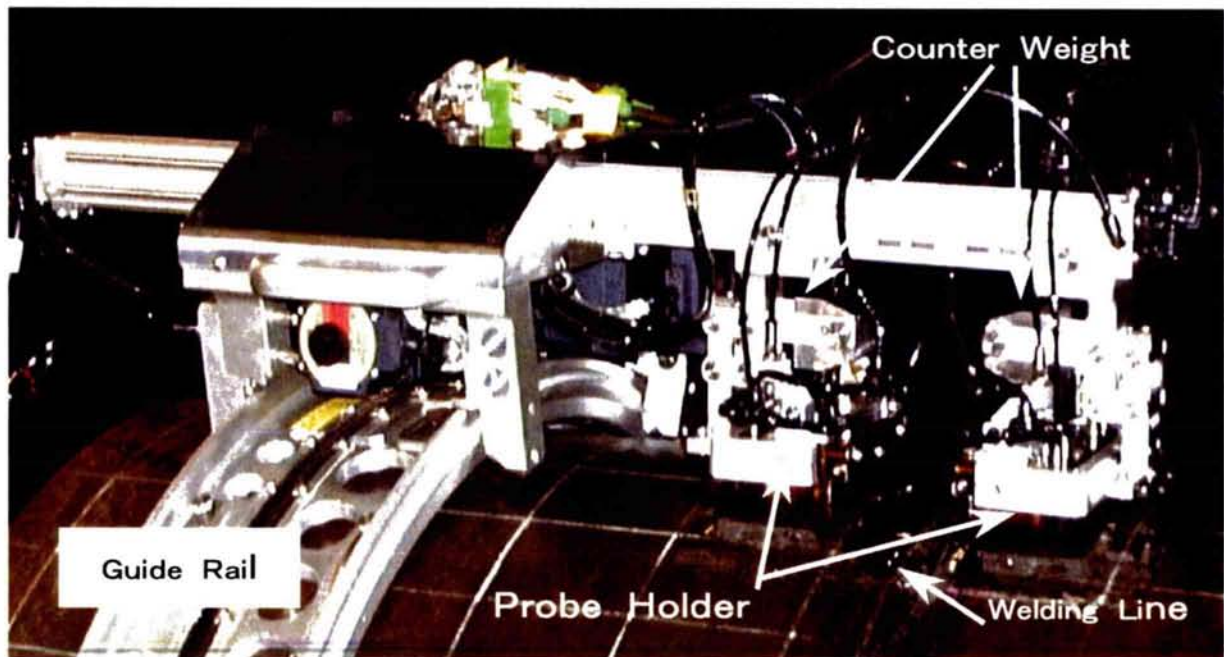


Fig. 2-14 Appearance of the Flaw Detection Unit

<Scanning Unit>

The Guide Rail can be attached to the pipe easily, on which the traveller equipped scanning probes runs smoothly.

This guide rail is the same as that of the welding head of the automatic welding machine, therefore, it takes little time to start inspection process after finishing welding process.

<32CH High-Speed Zigzag Scan Probes>

There are 32CH zigzag scan probes equipped in the both side of the welding line, which run around the pipe within five minutes.

② Device of variable incidence angle

Because the angle of reflection varies according to the manufacturing

conditions of the pipe and the ambient temperature, a special holder has been developed for the purpose of making the incident angle variable as shown in Fig. 2-15.

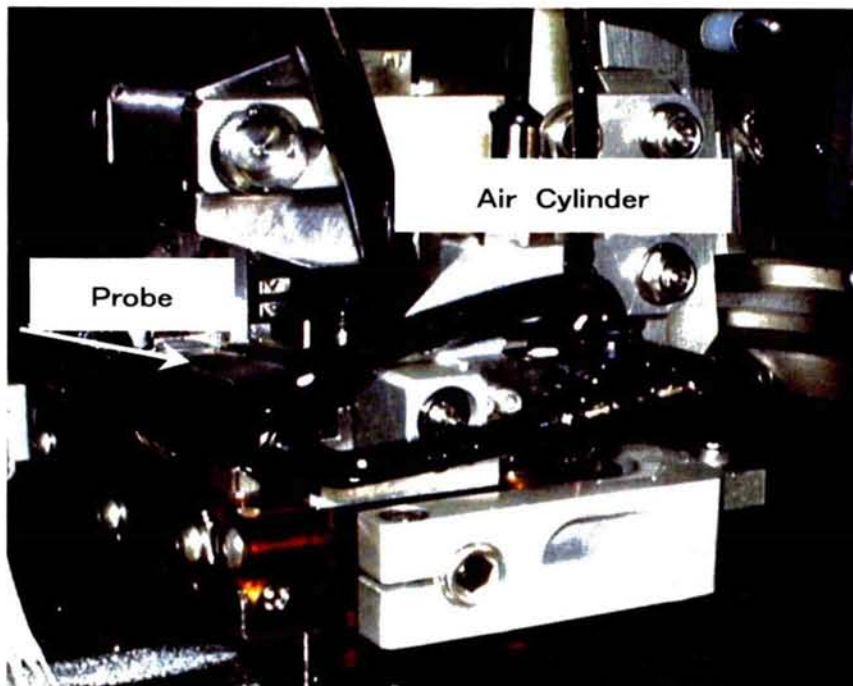


Fig. 2-15 Holder Device of Variable Incidence Angle

③ Coupling Check

As the method of coupling check the dendritic echo model which is regulated in JGA standard has been adopted.

When any coupling failure occurs, the portion will be inspected again automatically.

The coupling check method and the flow of corrective action is illustrated in Fig. 2-16, and an example of coupling check is shown in Fig. 2-17.

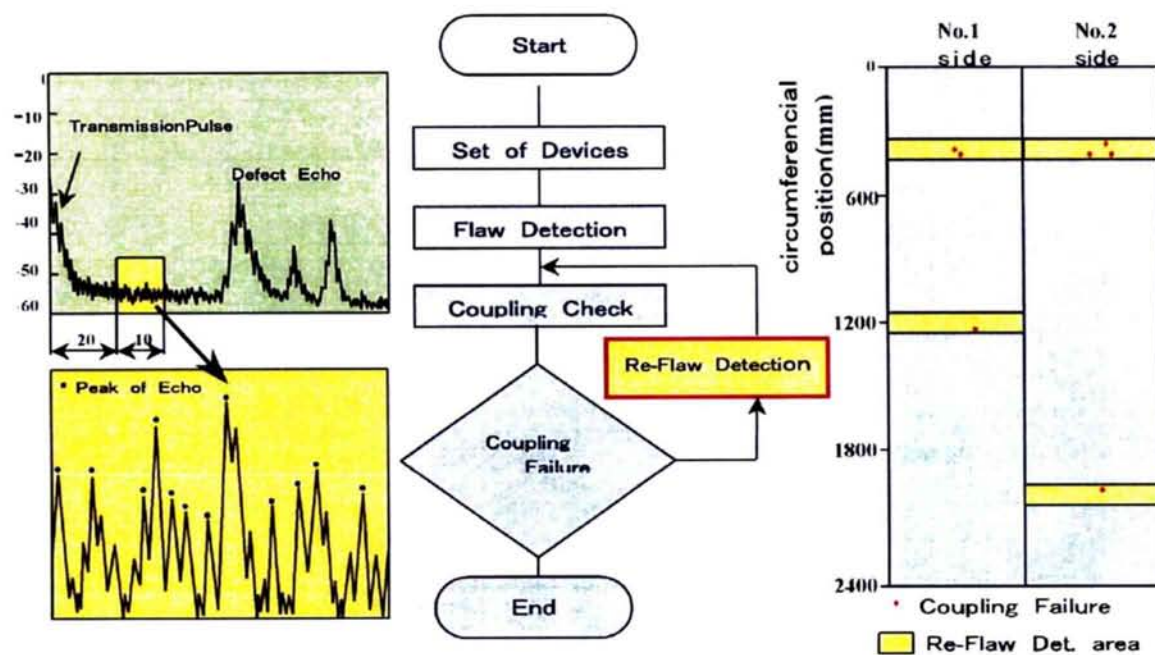
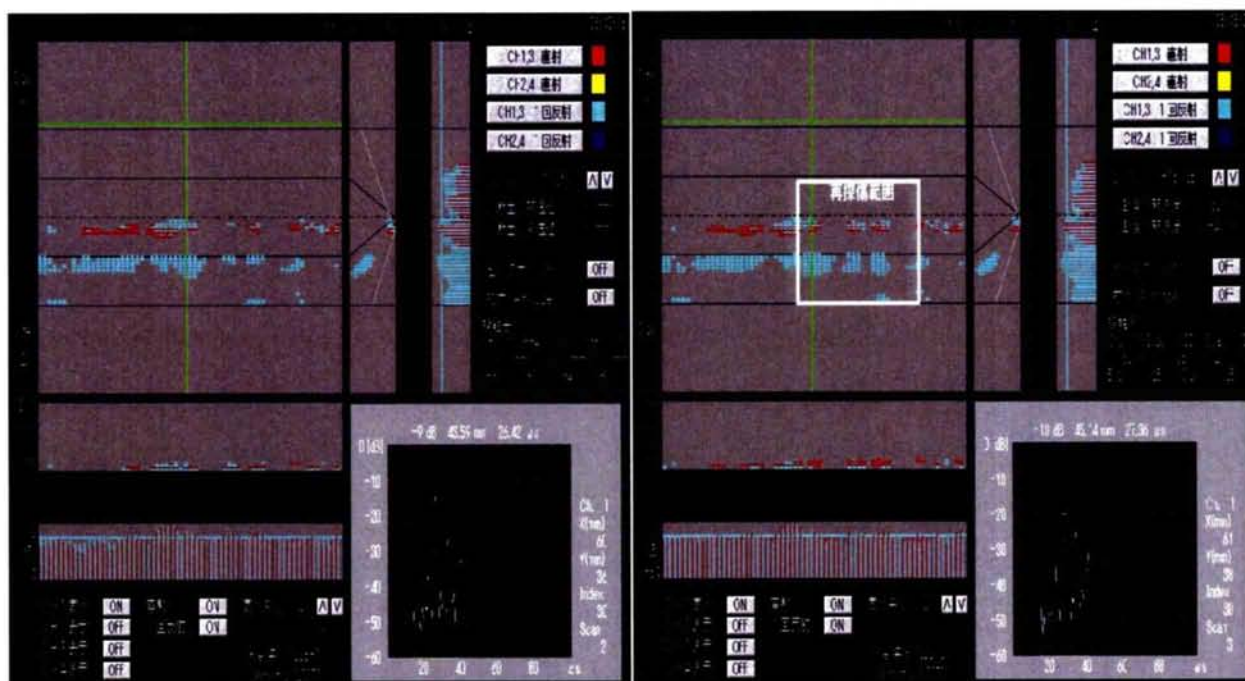


Fig. 2-16 Coupling Check Method



Screen with Coupling Failure

Screen after Re-Inspection

Fig. 2-17 Example of Coupling Check

④ Evaluation Testing of High-Speed Zigzag Scan UT System

<Flaw Detection Performance>

The accuracy of this system has been evaluated comparing with the result of elaborate manual detection which offers sufficiently reliable flaw data. The general conditions are listed in Table2-6.

Fig. 2-18 shows an example of automatical flaw detection by this system.

The comparison of the obtained results are summarized in Fig. 2-19 and Fig. 2-20, where scarce differences between the data of this system and that of manual flaw detection have been recongnized.

Thus the accuracy of this system has been assured.

Table2-6 General Conditions of Flaw Detection Performance

Test Piece	750A × 19mm
Refraction Angle	65°
Flaw Detection Method	Direct Ray or Single Bounce Tech.
Deta Record Pitch	2mm
Artifitial Defect (Mother Metal)	$\phi 3$ (Side,t/2) $\phi 4 \times 4$ (Both Surface) Slit($\phi 4$ mm, 30mmL, Both Surface)
Weld Defect (Weld Zone)	Lack of Penetration : 38mmL 4G※ Lack of Fusion(Small): 3mmL 1G※ Lack of Fusion(Large): 28mmL 4G※ Blowhole : 38mmL 4G※

※ Classification by JIS Z 3104

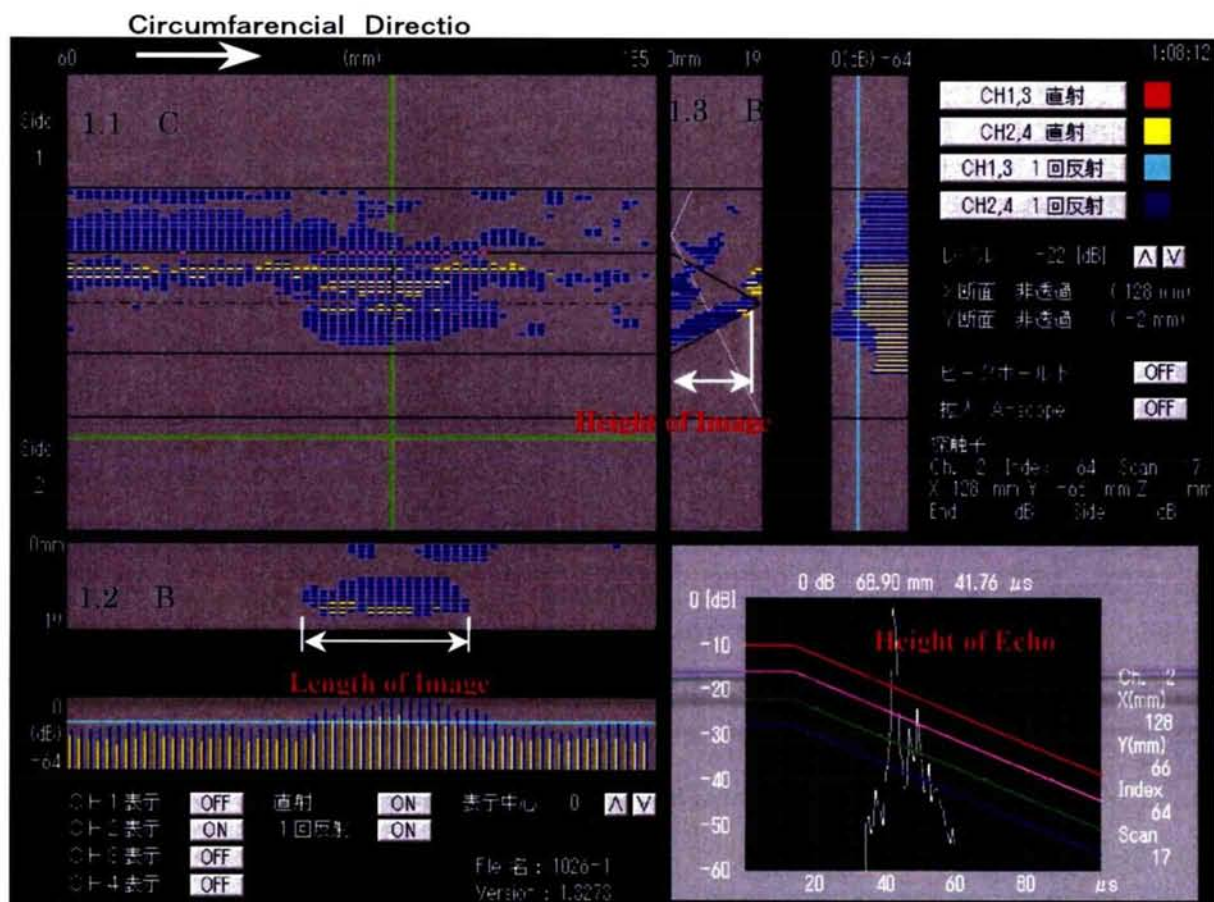
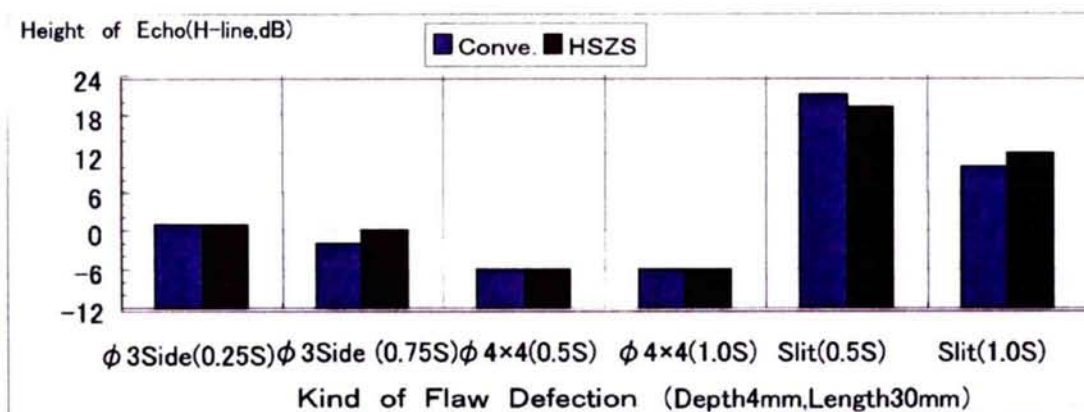
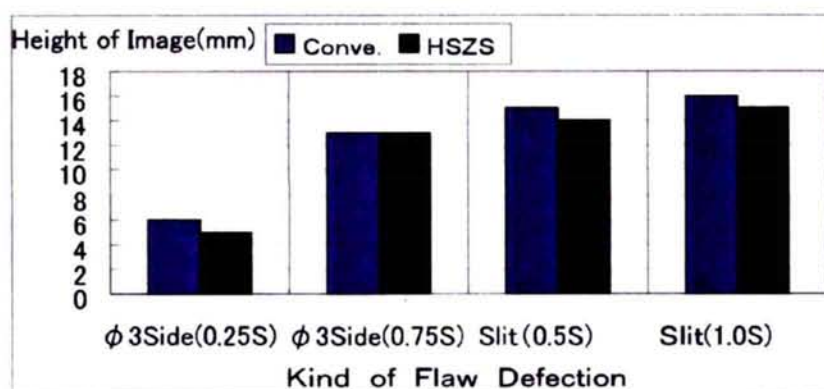


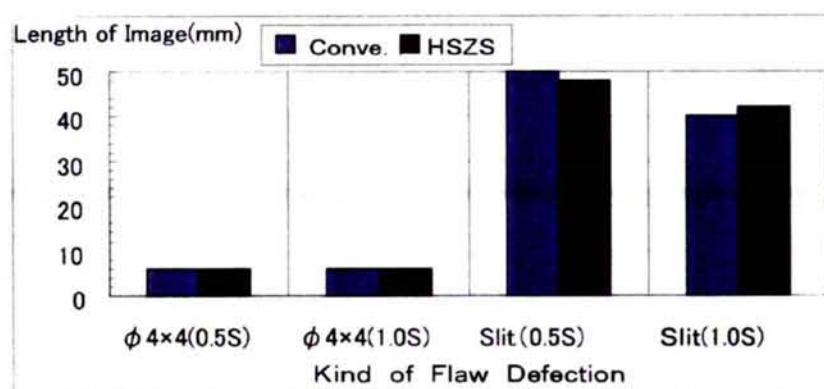
Fig. 2-18 Example of Automatical Flaw Detection



(a) Max. Height of Echo

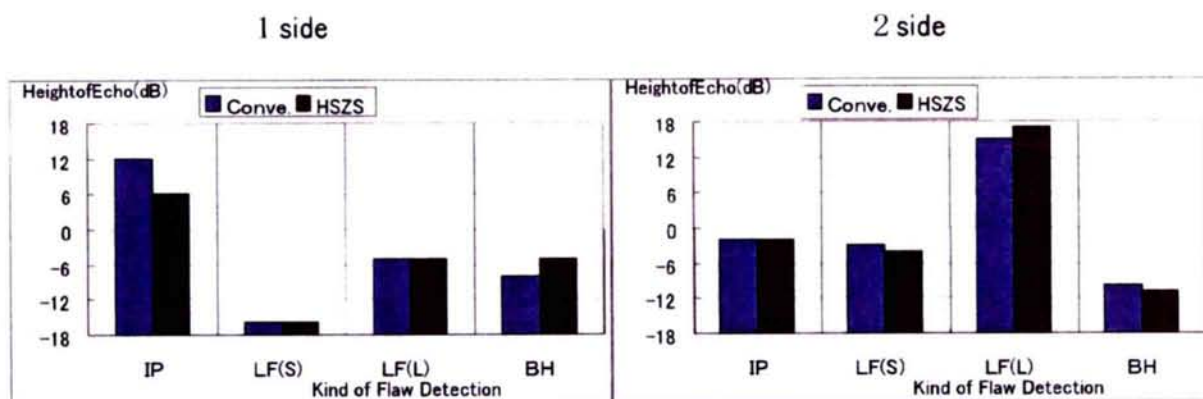


(b) Height of Image

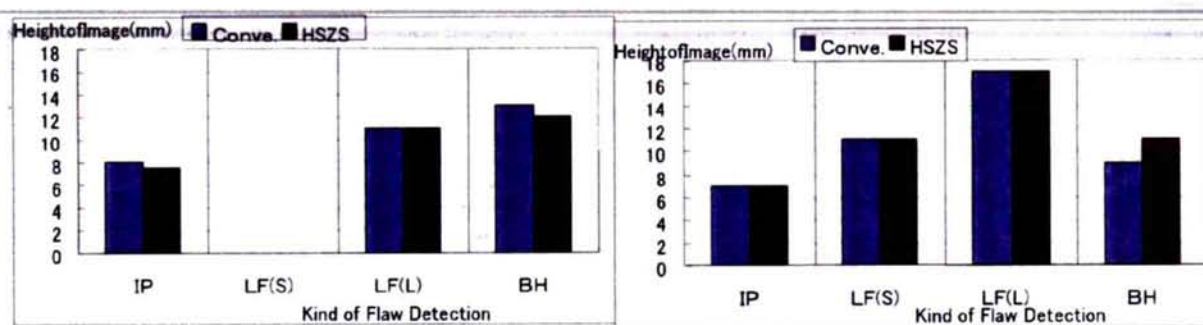


(c) Length of Image

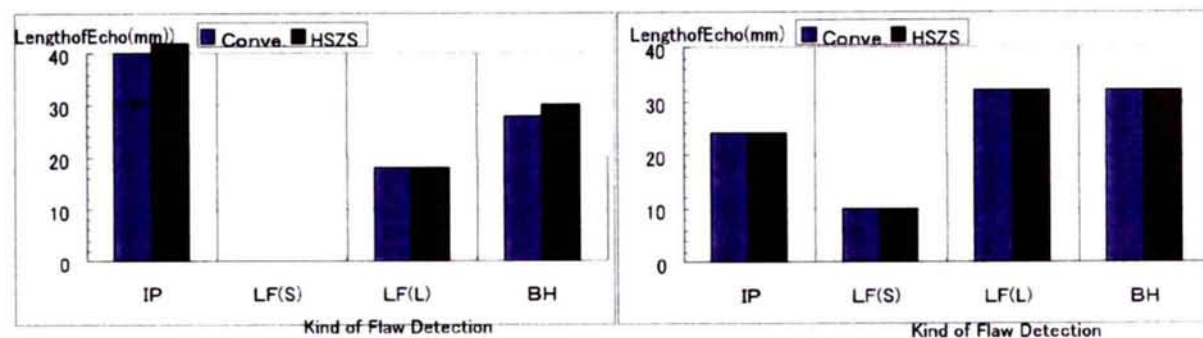
Fig.2-19 Comparison of the Results(Mother Metal)



(a)Max. Height of Echo



(b)Height of Image



(c)Length of Image

Fig.2-20 Comparison of the Results(Weld Zone)

<Inspection Time>

The total inspection time by an inspector from setting of the flaw detection device to execute coupling check has been measured as shown in Table2-7.

All the time of flaw detection is 110 seconds, and all the inspection time is only five minutes.

Table2-7 Inspection Time

Item	Test Result
Setting of Device	180 seconds
Flaw Detection	110 seconds
Coupling Check	10 seconds
Total	300 seconds

2.3 Automatic Field Coating System

(1) Corrosion Protection of Weld Zone

The weld zone of pipeline must be adequately coated by polyethylene tube, which consists of outer polyethylene layer and inner adhesion layer.

Fig. 2-21 and 2-22 show the outlook of weld zone before and after field coating.

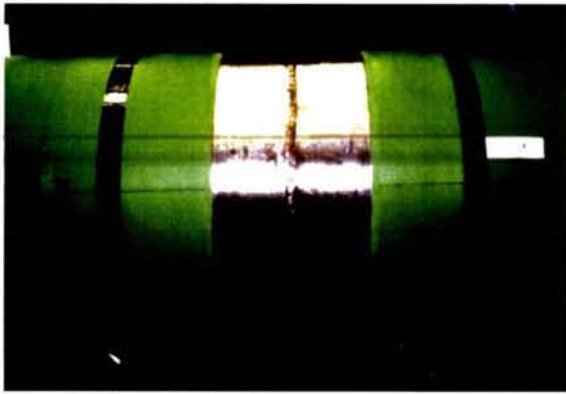


Fig. 2-21 Before Field Coating

Fig. 2-22 After Field Coating

(2) Conventional Procedure

Traditionally the tube has been heat-shrunk by skillful pipe fitters as shown in Fig. 2-23.

As the work itself is pretty difficult and very particular only in buried pipeline, the completed appearance must be strictly inspected.

Especially the air boid rest between the outer surface of the pipe and the inner side of the tube must be checked in order to assure the long-life soundness of the field coating.

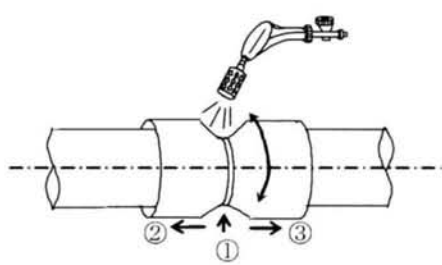


Fig. 2-23 Conventional Field Coating Work

(3) Outlook of Automatic Field Coating System

Recently, such skillful pipe fitters are getting less as well as skillful welders. In such a circumstance, Automatic Field Coating System has been developed in large diameter high-pressure natural gas pipeline. The features of the system can be summarized as below.

- Uniform shrinkage by infrared rays
- Boidless completion under vacuum circumstance
- Light weight and compact design
- Speedy and economical performance

The outlook of device is shown in Fig. 2-24.

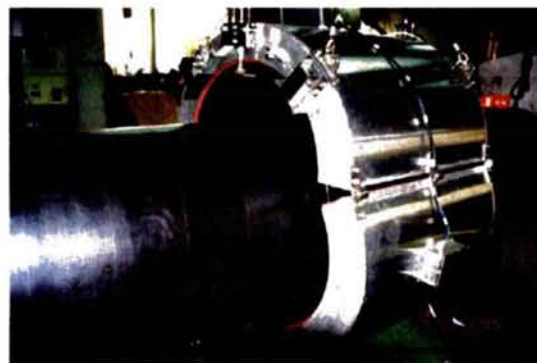


Fig. 2-24 Outlook of Automatic Field Coating System

(4) Result of performance test

- ① The performance of this system is superior to that of the conventional system in boidless adhesion.
- ② The heating time is only about 40 minutes in case of 600A and 750A.

Fig. 2-25 shows the adhesion of the field coating zone after removing the polyethylene tube.



Fig. 2-25 Adhesion of field coating

2. 4 Economical Non-Dig Construction System

(1) Increase of Non-Dig Construction System in Natural Gas Pipeline

In the field of earth works, Non-Dig Construction Systems such as Shield Tunnel System and Pipe Pushing System have been concretely adopted to construct road tunnels, sewerages and waterwoks.

Accompanying with the community development of large cities, the technology for small diameter tunnels has been rapidly developed especially in the sewerages. At the same time, it is getting difficult to dig the public roads to lay pipeline.

Non-Dig systems used to be adopted only in case of crossing obstacles, however, recently even along the road it might be adopted where the traffic problems are serious and/or there are so many obstacles in the underground.

Under such circumstances, the needs for Non-Dig Systems in the field of natural gas pipeline have been getting higher.

In general Pipe Pushing System is more economical than Shield Tunnel System because the facilities are more simple and the progress a day is much longer.

Moreover, the possible execution length has been risen up almost equal to Shield Tunnel System, the reasons of which might be summarized as follows(14).

- High-Strength hume concrete pipe has developed.
- High-quality skid which reduce the friction force between the pipe and the soil has been developed.

- Automatic measuring system has been developed.
- Multistage jack has been developed.

(2) Soil-Skid Mixed Pipe Pushing System

Soil-Skid Mixed Pipe Pushing System is one of the preceding Pipe Pushing Systems developed in 1993.

This system enabled long-distance pushing by mixing the skid into the surrounding soil as shown in Fig. 2-29.

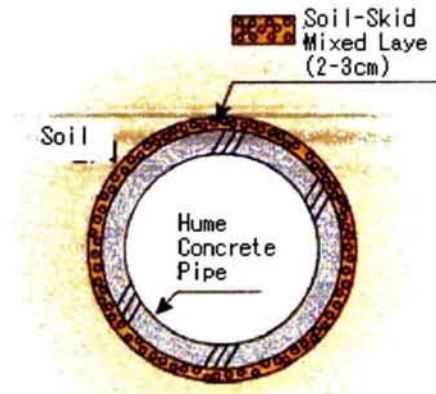


Fig. 2-29 Cross-Section of Soil-Skid Mixed Pushing

The features of this system are as follows.

- All automatic skid operation makes the control easy and stable.
(Fig. 2-30)
- Long-distance pushing is possible as shown in Fig. 2-31.

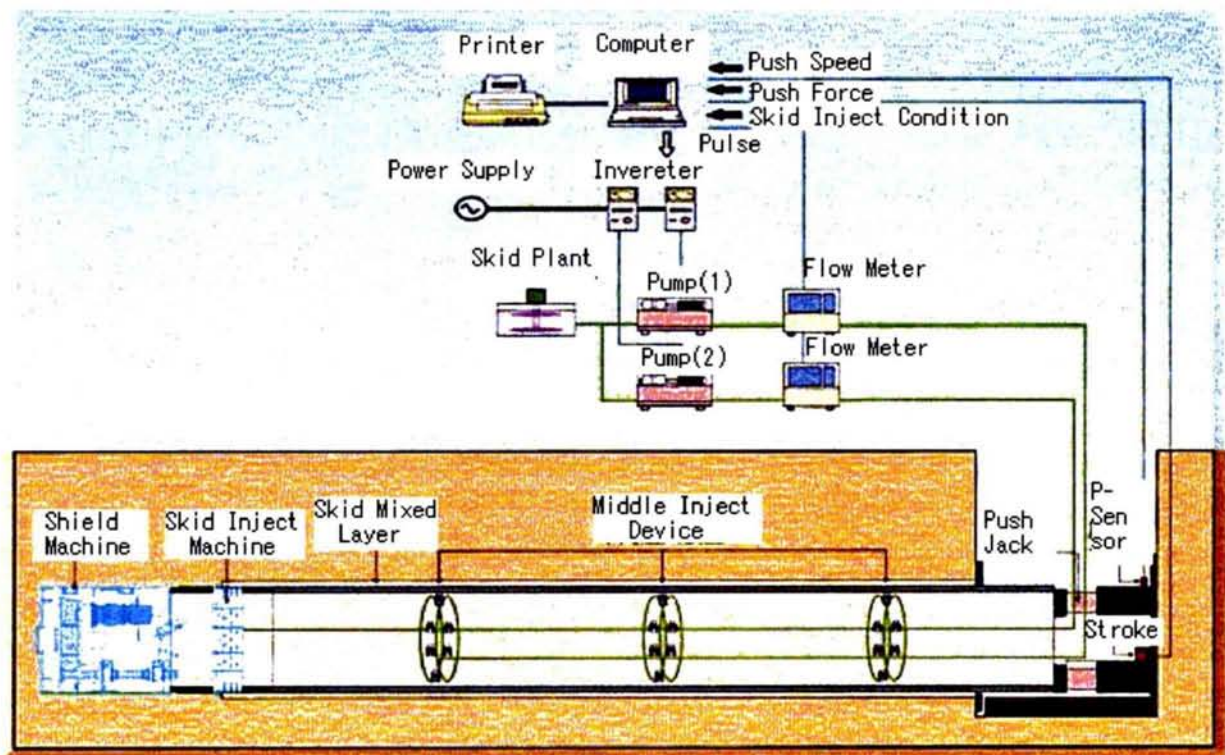


Fig. 2-30 Automatic Control System

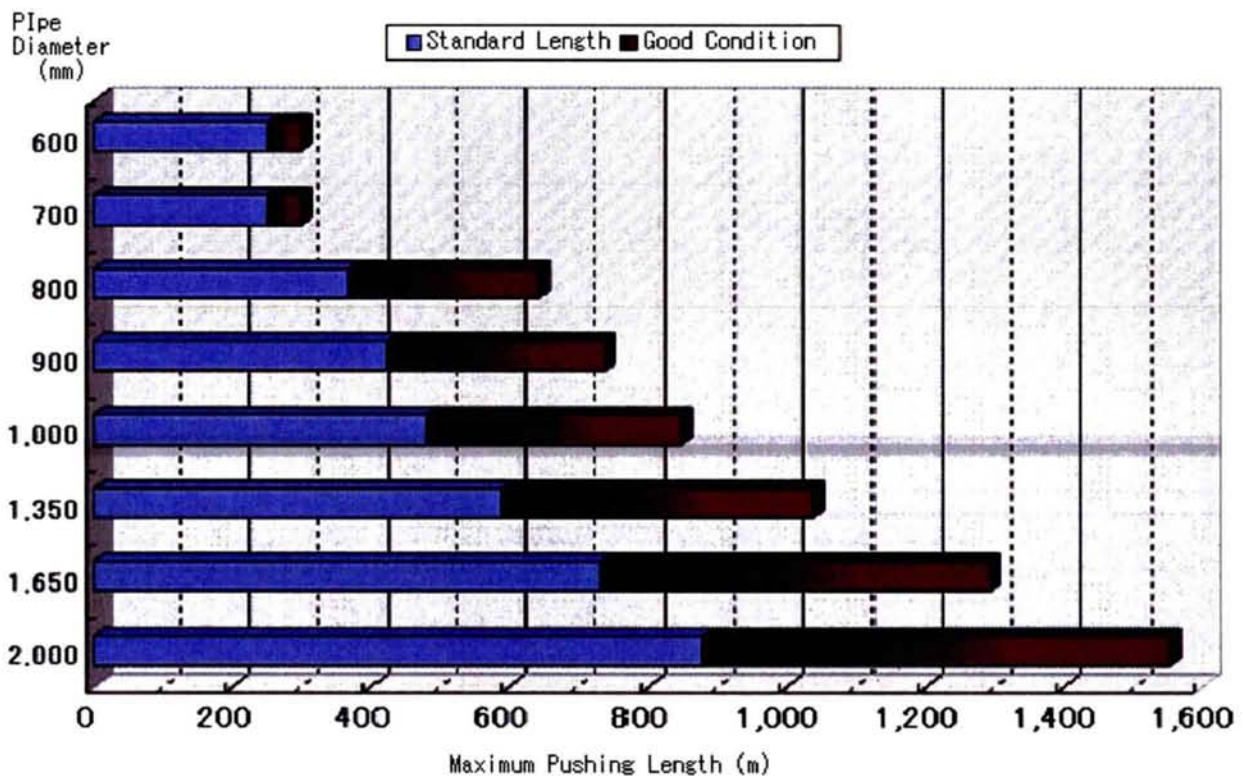


Fig. 2-31 Maximum Pushing Length

<Execution results of long-distance pipe pushing>

In 2001 the longest pipe pushing of huge pipe into which natural gas pipeline is pulled has been completed in Nagoya.

① Pipe Pushing System

The main conditions of Pipe Pushing System are shown in Table2-8.

Table 2-8 The Conditions of Longest-Distance Pipe Pushing

Item	Condition
Excavation Machine	Slurry Type Semi-Shield System
Diameter of Hume Pipe	1, 500mm
Total Pushing Length	749m
Depth of Hume Pipe	14. 4m ~ 16. 7m
Soil Components	Sand, Solidified Silt, Tokoname(N>50)

Using Soil—Skid Mixed Pipe Pushing System, the pushing force has gotten about one third of usual system as shown in Fig. 2-32.

Pushing Force (Ton)

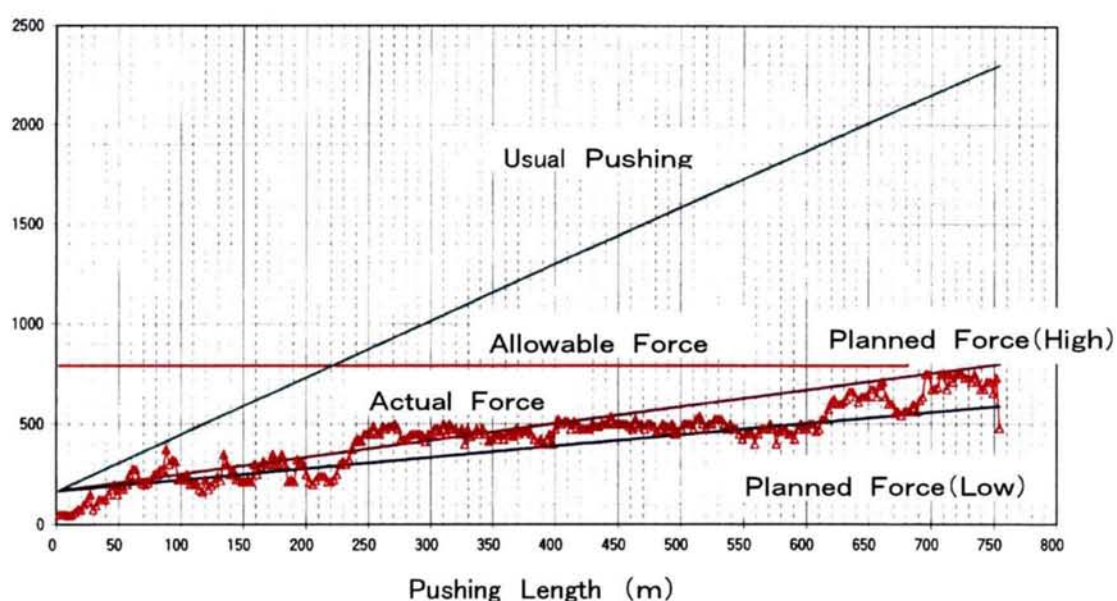


Fig. 2-32 Results of Pushing Force

② Specifications of natural gas pipeline

The specifications of natural gas pipeline and pulling method into the hume pipe are shown in Table2-9.

The Wheeled Resin Pipe Support has been designed and adopted not to injure outer coating during pulling periods as shown in Fig. 2-33.

Table 2-9 Specifications of Natural Gas Pipeline and Pulling Method

Item	Specification
Design Pressure	7MPa
Diameter and Wall-Thickness	750A, 20. 5mm
Outer Coating	Polyethylene Coating
Pulling Method	Electromotive Chain Hoist
Pipe Support Method	Wheeled Resin Pipe Support

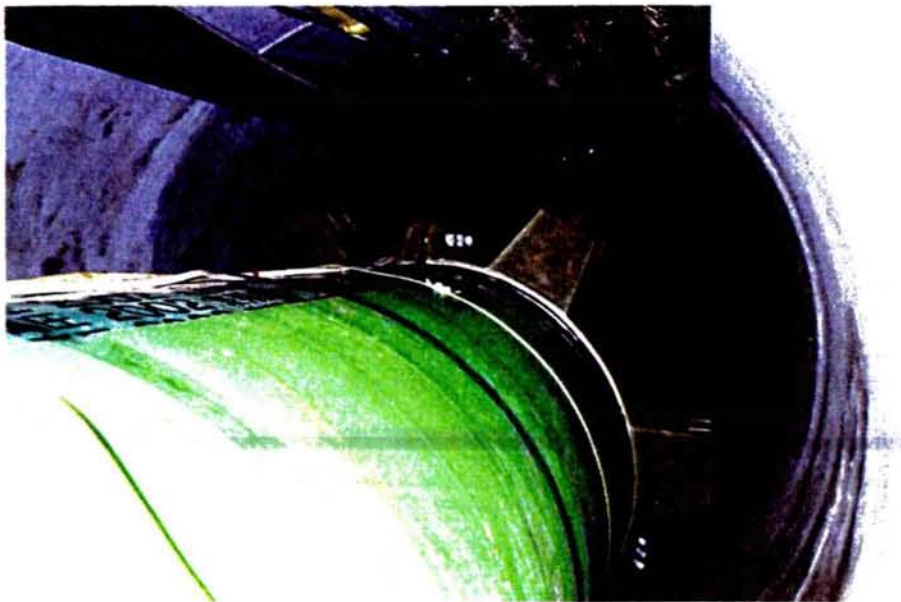


Fig. 2-33 Pulled Pipe with Wheeled Resin Pipe Support

2. 5 Combination of Each System

Pipeline construction activities are composed of various items as follows, and best combination must be considered to make the safe and economical pipeline.

- Selection of material members
- Selection of welding procedures
- Selection of inspection specifications
- Selection of coating systems
- Selection of adequate earth works

(1) Selection of material members

Pipe material specification may be followed in the Table1-5 because the API Specification will be able to provide sufficient design items so far as the present pressure conditions do not change.

The biggest problem is how to determine the specification of bent pipe because there is not any code of bent pipe.

Especially in Japan, the configuration of the road where the pipeline is buried has a lot of curved portions.

Therefore, the adequate bent pipe combination must be planned using cold bent pipe, hot bent pipe and S-type bent pipe.

(2) Selection of welding procedures

The welding process in the field is as important as the pipe material because the pipeline must be guaranteed as a total structure including site connections.

Under present conditions shield metal arc welding(SMAW) by welders is popular in the field weld.

And it is necessary that the welding procedure specification(WPS) should be planned and ascertained in advance in order to achieve the high quality of the welding.

The following three main items must be described in the WPS.

- Welder qualification
- Welding facilities
- Welding procedure

As the field welding quality depends on the skill of the welders, the control of the welders is very significant to keep good welding grade constantly.

As explained in this chapter, automatically controlled welding machines have been developed especially in large diameter High-Pressure pipeline. Aiming at high cost performance, the adequate selection of automatic welding system must be planned among various types of automatic welding system according to the laying conditions of the pipeline.

(3) Selection of inspection specifications

The quality of the field welding should be ascertained by non-destructive inspection such as radiographic testing(RT) and ultrasonic testing(UT).

Only RT was provided as an established testing of the field welding in The Gas Utility Industry Law so far, but UT is newly authorized as an alternative testing method on April 1st, 2004.

Therefore, the adequate inspection selection must be considered from now on to complete sound and economical pipeline.

(4) Selection of coating systems

The life of underground steel pipeline against corrosion is attained by pipe coating and cathodic protection.

The field weld portions are necessarily coated by polyethylene tube or tape after welding process. The quality control of this field coating is very important because it influences the total life of pipeline greatly.

It is recommended that the automatic field coating system should be adopted to keep the quality constant without differences between individuals.

After completion the electric potential of pipeline must be kept under anti-corrosion potential value by the cathodic protection procedure such as sacrifice anode procedure and impressed current procedure.

When the provision against corrosion are executed safely and surely, the pipeline shall survive almost forever.

(5) Selection of adequate earth works

The laying conditions of natural gas pipeline in Japan is fully different from that in the foreign countries.

That is, in almost all of the foreign countries natural gas pipeline is to be constructed within an exclusive laying site called "Right Of Way" (ROW) where all the obstacles are removed before construction works begin.

Therefore the pipeline laying system in ROW has been developed to be the most speedy system called "Spread Construction System".

A lot of special machines and labours make pipeline construction progress about two or three km a day easily.

On the contrary, in Japan natural gas pipeline is usually buried only under public roads. Of course the traffic is so heavy on the street that the construction can not help being restricted in the aspects of the working time, the working area and the way of construction itself.

Moreover existing facilities under concerned streets sometimes make the construction progress less and less.

Under such surrounding conditions, it is very significant to select the combination of earth works to construct natural gas pipeline including the non-dig system.

The open cut system is usually adopted, and it is more speedy and economical than the non-dig system.

As explained in this chapter, however, as the non-dig system has been getting more economical, the adoption of non-dig systems will increase more in the near future.

Chapter 3 Feasibility Study for High-Pressure Natural Gas Supply System

According to the increase of commercial use of natural gas, higher pressure supply to the customers has been getting more advantageous than usual low-pressure or middle-pressure supply from the viewpoint of efficiency.

Middle-pressure direct supply system has been already popularized to large-lot customers such as manufacturing plants, hospitals, water purification plants and other facilities.

In case of middle-pressure direct supply system, the reliability against earthquakes has been heightened by the use of steel pipe as well as transportation efficiency.

Moreover, because the quantity of natural gas gets pretty large in case of on-site power plants including CGS systems, the superiority and efficiency of high-pressure supply have been getting the hot focus of attention by the natural gas suppliers. This new system for large-lot natural gas customers will increase more in parallel with the further popularization of CGS by natural gas.

The merits of the high-pressure supply system from the viewpoint of construction cost of pipeline has been investigated as follows.

(1) Determination of Pipe Diameter

The diameter of middle-pressure and high-pressure pipeline can be calculated by the formula as follows(15).

$$D = \left[(Q/K)^2 \left\{ SLg^2 / (10,000(P_1^2 - P_2^2)) \right\} \right]^{1/5}$$

$$Q = K \left((10,000(P_1^2 - P_2^2)D^5) / SLg^2 \right)^{1/2}$$

where

D : diameter of pipeline (cm)

Q : natural gas flow quantity (m³/h)

L : length of pipeline (m)

P₁ : absolute pressure of the starting point (MPa)

P₂ : absolute pressure of the end point (MPa)

S : specific gravity of natural gas

g : acceleration of gravity (9.80665m/s²)

K : flow coefficient

$$K = 37.67D^{1/6} \quad (\text{Weymouth Formula})$$

(2) Relationship between Pipe Diameter(D) and Pressure(P₁)

The necessary diameters have been calculated under some conditions of transportation using the formula above.

① In case that P₂ may be relatively low pressure(P₂=0.5)

Fig. 3-1 shows the relationship between the absolute pressure of starting point (P₁) and the necessary diameter of pipeline (D) with the parameter of the length of pipeline (L) when the natural gas flow quantity (Q) is relatively large.

In this case P₁ is assumed to be 1MPa, 2MPa, 4MPa and 7MPa which is the standard design pressure.

In Fig. 3-2 the same relationship is shown when the natural gas flow quantity (Q) is smaller than that in Fig. 3-1.

From the figures the following knowledges are easily gotton.

- When the flow quantitiy of natural gas (Q) is relatively large, the diameter of pipeline is greatly influenced by the pressure of starting point(P_1) regardless of the pipeline length(L).
- On the contrary, when the flow quantitiy of natural gas (Q) is relatively small and the pipeline length(L) is relatively short, the diameter of pipeline does not get smaller by raising up the the pressure of starting point(P_1).

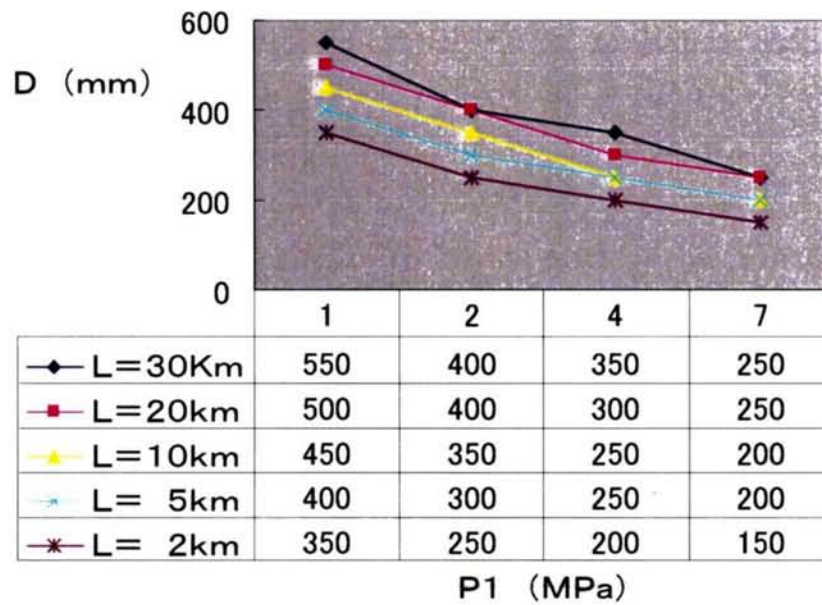


Fig. 3-1 Relationship between D and P1 ($Q=100,000\text{m}^3/\text{h}$)

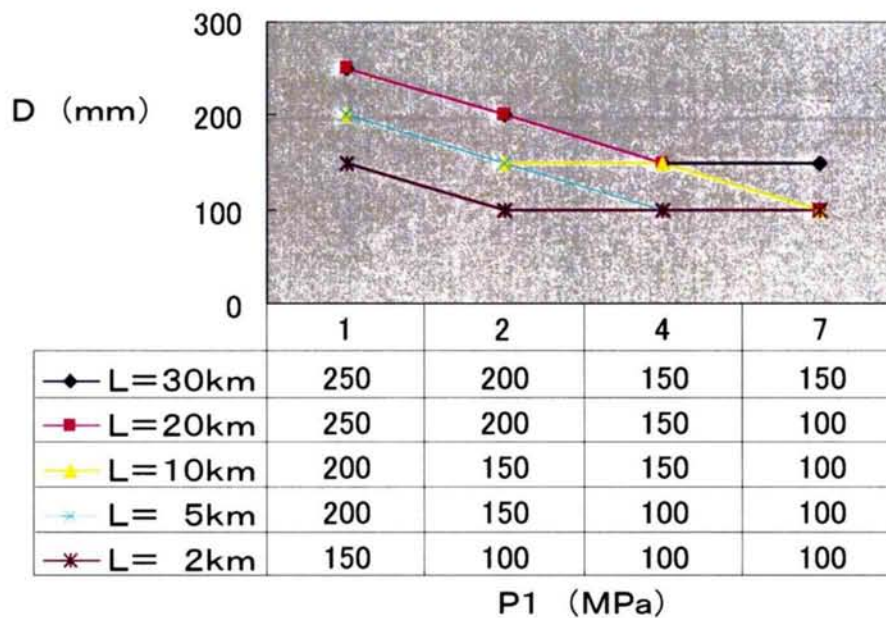


Fig. 3-2 Relationship between D and P1 ($Q=10,000\text{m}^3/\text{h}$)

② In case that P2 must be higher pressure($P_2=1.0$)

Because the the pressure of end point(P_2) must be higher than that of in the former case, the absolute pressure of starting point (P_1) is limited to high pressure.

Fig. 3-3 and Fig. 3-4 show the relationship between the absolute pressure of starting point (P_1) and the necessary diameter of pipeline (D) with the parameter of the length of pipeline (L) when the natural gas flow quantity (Q) is relatively large and small, respectively.

In this case P_1 is assumed to be 2MPa, 4MPa and 7MPa.

From these figures the same tendency as in the low end pressure is confirmed as follows.

- When the flow quantity of natural gas (Q) is relatively large, the diameter of pipeline is greatly influenced by the pressure of starting point(P_1) regardless of the pipeline length(L).
- On the contrary, when the flow quantity of natural gas (Q) is relatively small and the pipeline length(L) is relatively short, the diameter of pipeline doesn't get smaller by raising up the pressure of starting point(P_1).

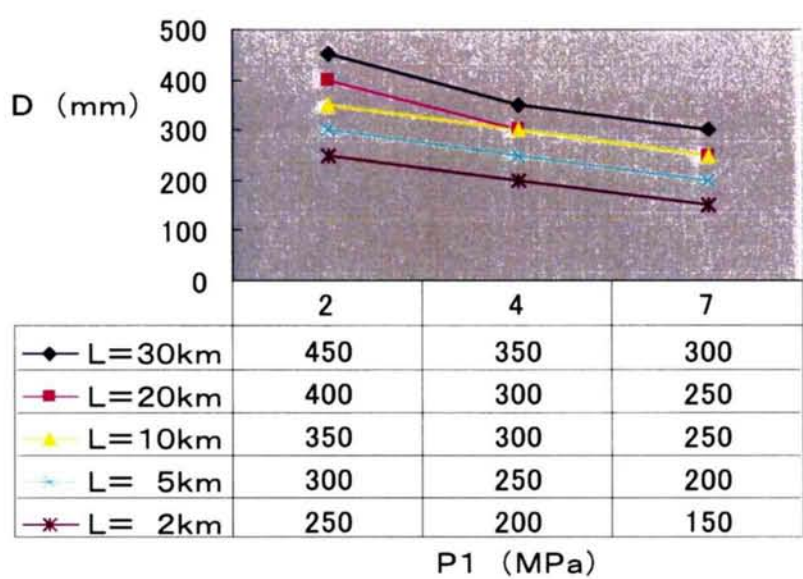


Fig. 3-3 Relationship between D and P1 ($Q=100,000\text{m}^3/\text{h}$)

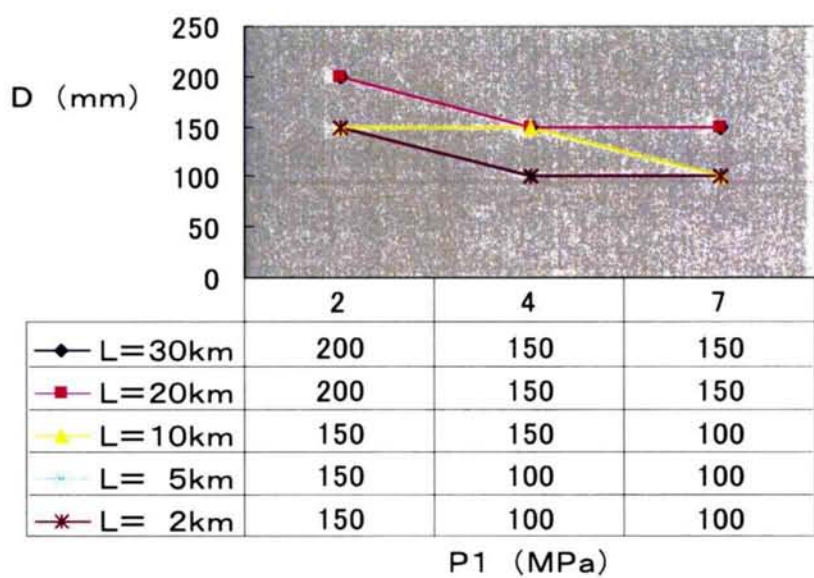


Fig. 3-4 Relationship between D and P1 ($Q=10,000\text{m}^3/\text{h}$)

③ In case that P2 must be much higher pressure($P_2=2.0$)

Because the pressure of end point (P_2) is high-pressure in this case, the absolute pressure of starting point (P_1) is limited to be 4MPa and 7MPa.

Fig. 3-5 and Fig. 3-6 show the relationship between the absolute pressure of starting point (P_1) and the necessary diameter of pipeline (D) with the parameter of the length of pipeline (L) when the natural gas flow quantity (Q) is relatively large and small, respectively.

From the figures above the same tendency as in the former cases is also confirmed as follows.

- When the flow quantity of natural gas (Q) is relatively large, the diameter of pipeline is greatly influenced by the pressure of starting point(P_1) regardless of the pipeline length(L).
- On the contrary, when the flow quantity of natural gas (Q) is relatively small and the pipeline length(L) is relatively short, the diameter of pipeline does not get smaller by raising up the pressure of starting point(P_1).

In all transportation conditions as shown in from Fig. 3-1 to Fig. 3-6, the diameter of pipeline can be reduced obviously by heightening the operating pressure when the natural gas quantity gets large.

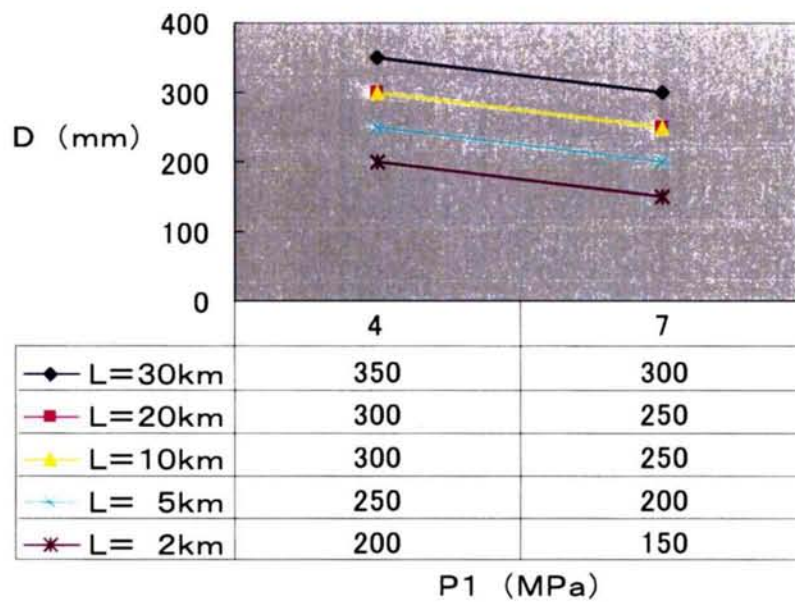


Fig. 3-5 Relationship between D and P1 ($Q=100,000\text{m}^3/\text{h}$)

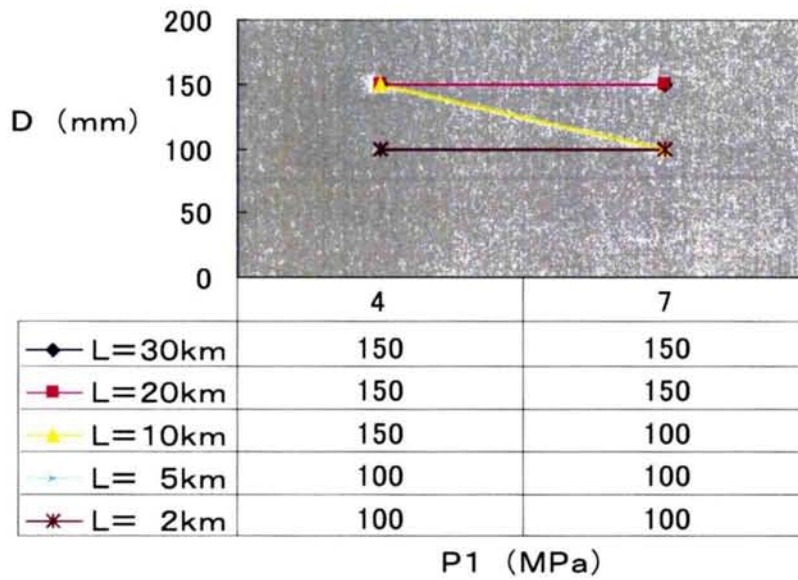


Fig. 3-6 Relationship between D and P1 ($Q=10,000\text{m}^3/\text{h}$)

(3) Cost Reduction Effects of Heightening the Pressure

The necessary pipe diameter can be reduced by heightening the design pressure as culculated in the former passage.

Although the design specifications are different according to the design pressure, the cost of pipeline construction is mainly influenced by the size of diameter.

Concrete cost reduction effects by heightening the pressure have been examined in some transportation conditions.

① Relationship between Construction Cost and Pipeline Diameter

In general the influence of pipeline diameter agaist construction cost can be supposed to be as follows.

- Material cost of pipe is proportional to the weight of pipe.
(Extra cost according to the grade of pipe is necessary.)
- Piping cost is proportional to the diameter of pipe.
(Wall thickness should be considered.)
- Earthwork cost is proportional to the digging volume.
- Admistarative cost is proportional to the direct costs and the construction period.

Based on these suppositions the relationship between construction cost and pipeline diameter might be calculated as Fig. 3-7 in case of HP and MP, respectively.

In this figure construction cost is presented by Cost Index which is the ratio of construction cost against that of 300A MP pipeline.

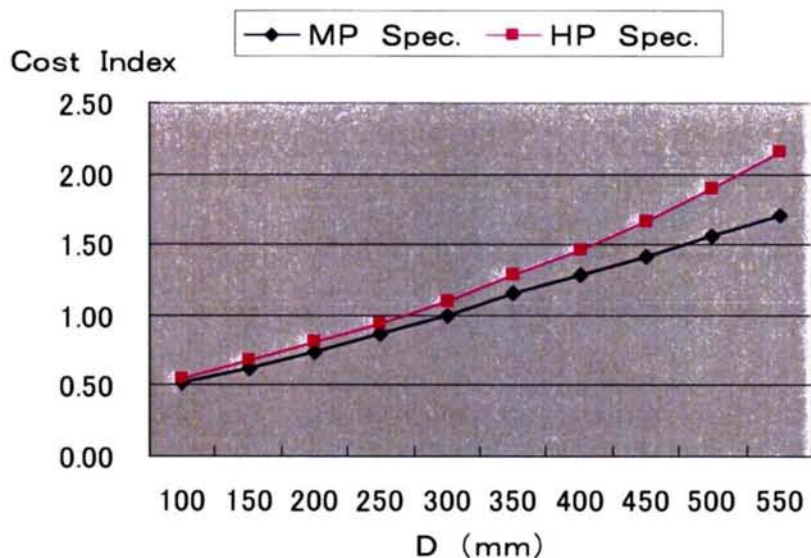


Fig. 3-7 Relationship of Cost Index and Diameter(D)

(4) Best Cost Performance selecting Design Pressure

In designing the pressure, the best cost performance can be get the former figures from Fig. 3-1 to Fig. 3-6 and Fig. 3-7.

The results from the cost investigation are summarized as follows.

- ① When the flow quantity of natural gas (Q) is relatively large, the construction cost will reduce selecting the higher design pressure.
- ② The cost reduction effects selecting the higher pressure will get 20% and over compared with that of low design pressure.
- ③ When the flow quantity of natural gas (Q) is relatively small, the cost reduction effects selecting the higher design pressure will not be expected.

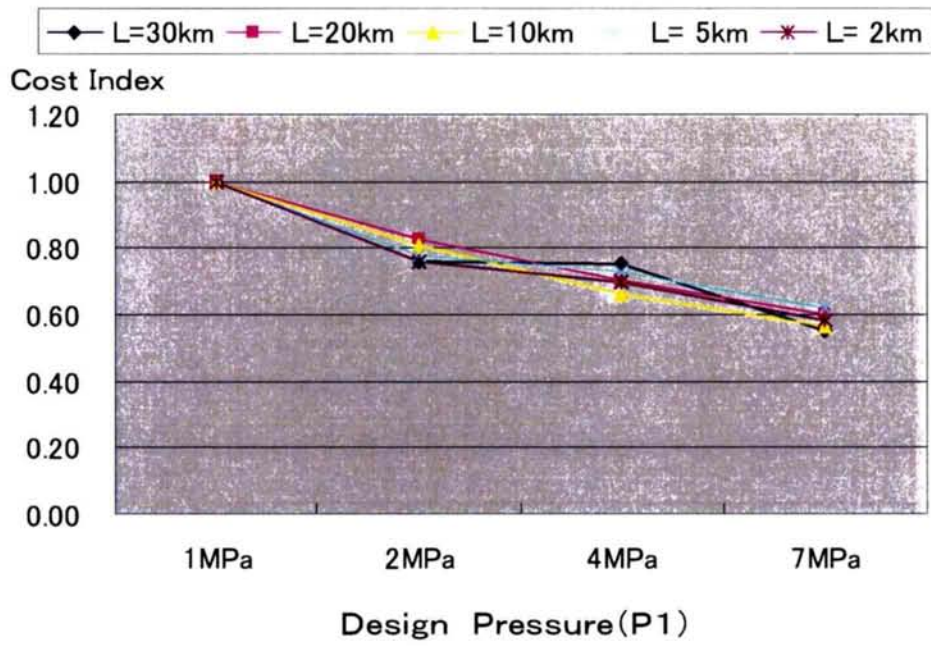


Fig. 3-8 Cost Comparison with Design Pressure
($Q=100,000\text{m}^3/\text{h}$, $P_2=0.5$)

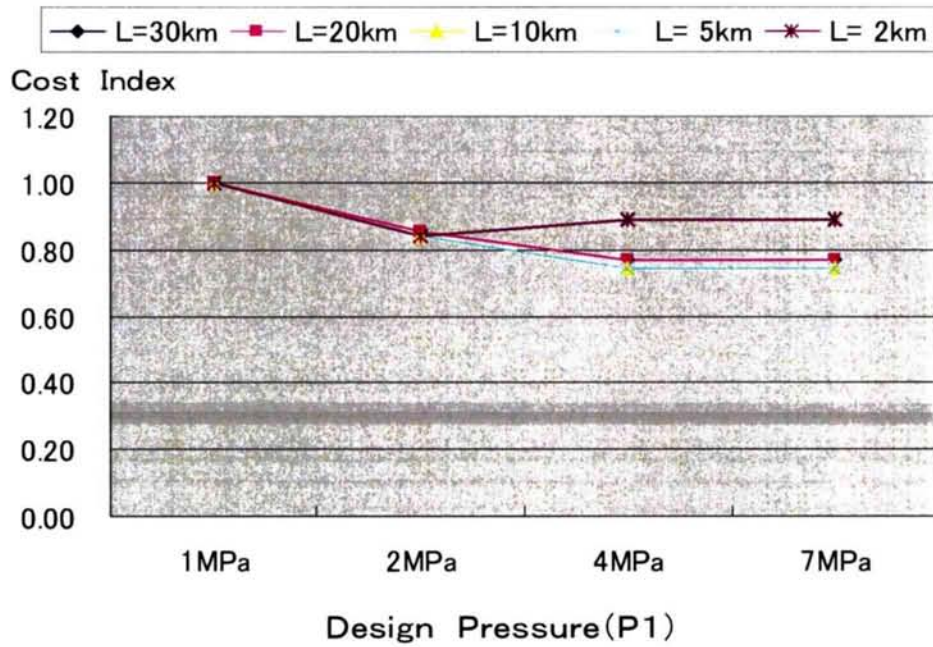


Fig. 3-9 Cost Comparison with Design Pressure
($Q=10,000\text{m}^3/\text{h}$, $P_2=0.5$)

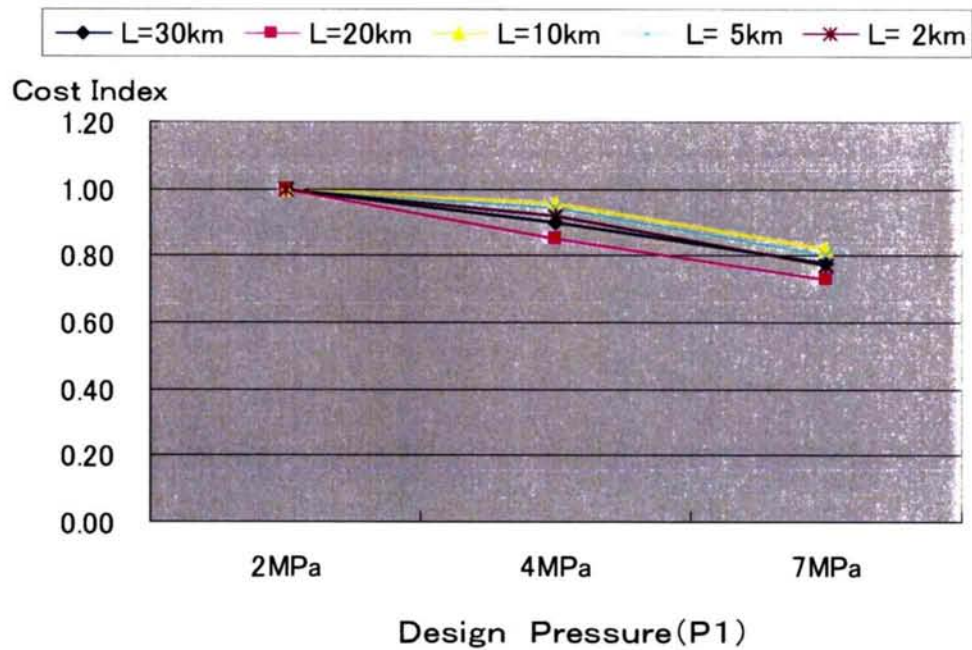


Fig. 3-10 Cost Comparison with Design Pressure
($Q=100,000\text{m}^3/\text{h}$, $P_2=1.0$)

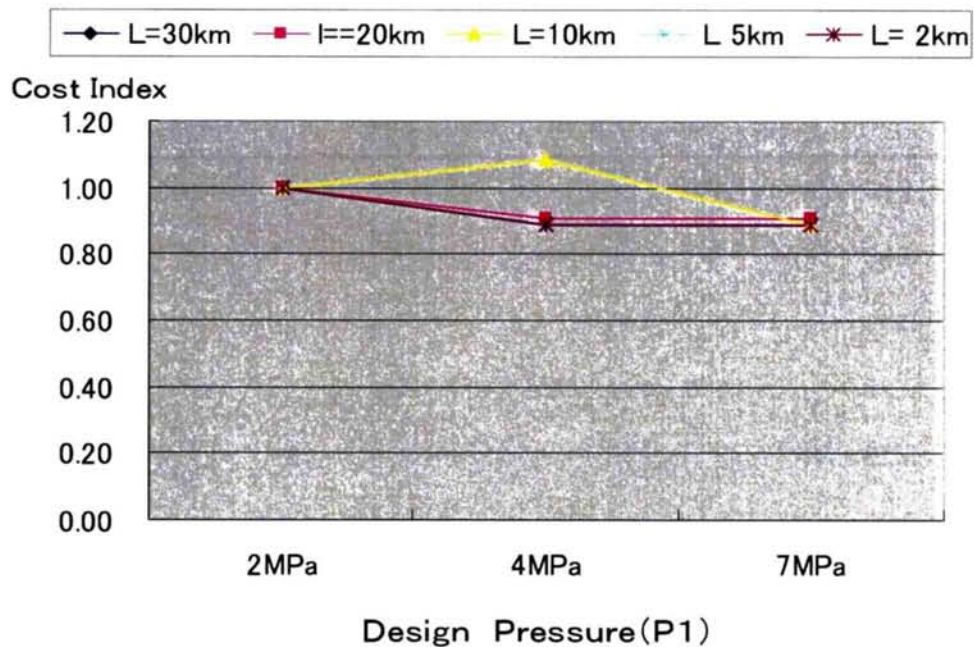


Fig. 3-11 Cost Comparison with Design Pressure
($Q=10,000\text{m}^3/\text{h}$, $P_2=1.0$)

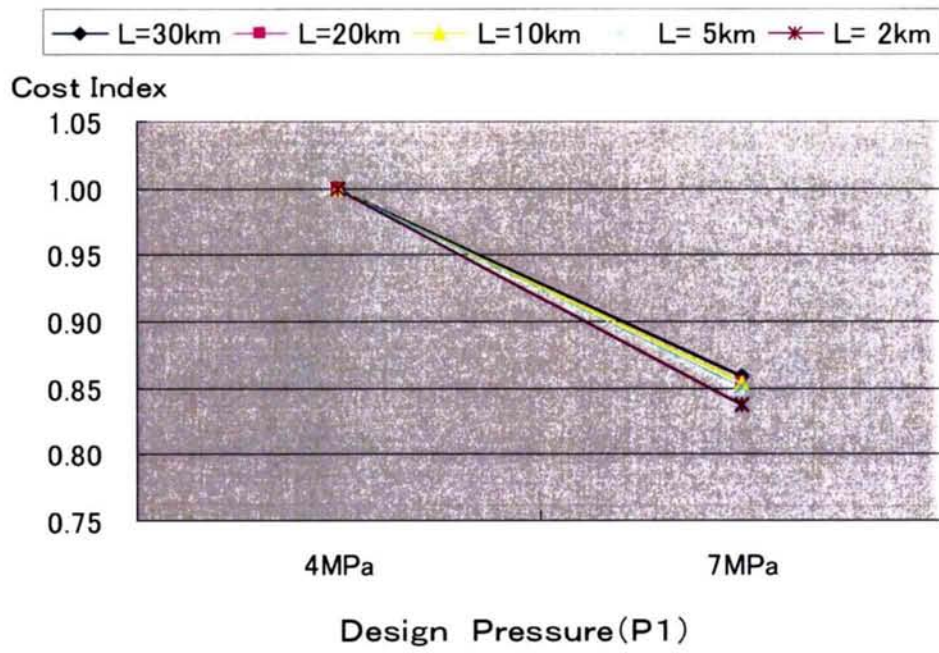


Fig. 3-12 Cost Comparison with Design Pressure
($Q=100,000\text{m}^3/\text{h}$, $P_2=2.0$)

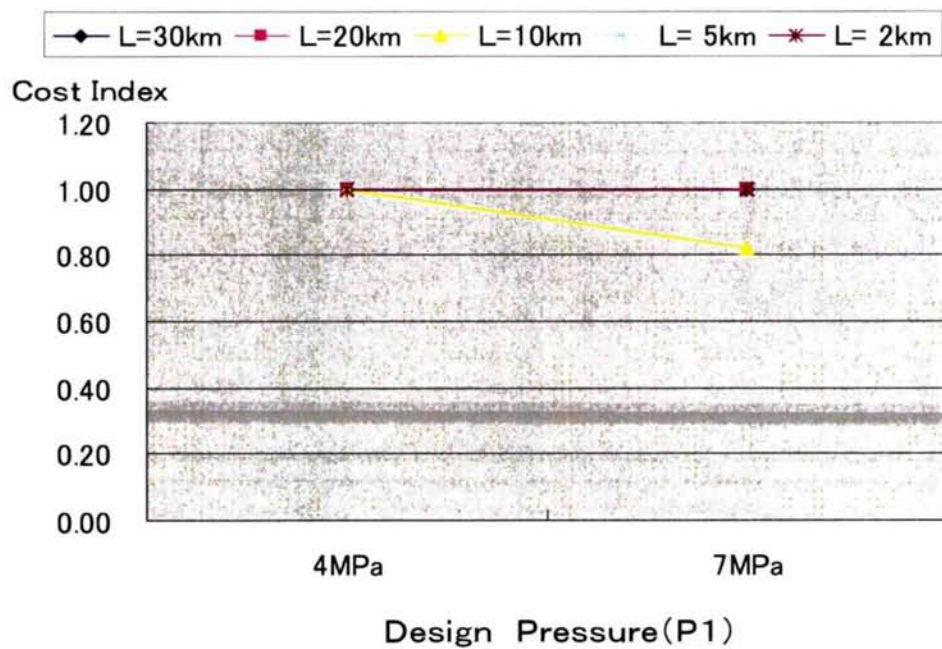


Fig. 3-13 Cost Comparison with Design Pressure
($Q=10,000\text{m}^3/\text{h}$, $P_2=2.0$)

Chapter 4 Development of New LNG Pipeline System

Austenitic stainless steel is the most common material for the pipe used to transport liquefied natural gas(LNG) up to the present.

When the stainless steel pipe is subject to thermal contraction under low temperature conditions, heat-stress absorption systems such as loop piping are necessary in adequate intervals.

The whole construction cost of piping gets pretty expensive because the welding and insulation works increase by such loop piping.

Moreover, the wide installation space for piping must be prepared.

Invar Alloy piping system has been developed in order to resolve such problems of LNG pipeline and piping.

4. 1 Development of Invar Alloy Pipeline System

(1) Features of Invar Alloy

Fig. 4-1 shows the relationship between Ni content of Fe-Ni alloy and the coefficient of linear expansion. When the content of Ni is 36%, the coefficient of linear expansion indicates the minimum value.

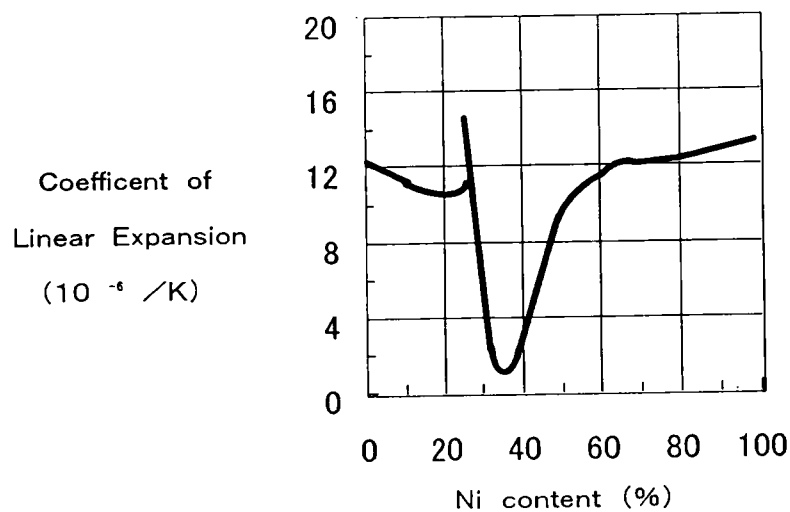


Fig. 4-1 Coefficient of Linear Expansion of Fe-Ni Alloy

Invar Alloy consists of 64% iron (Fe) and 36% nickel (Ni), which has a coefficient of linear expansion of approximately one-tenth compared with stainless steel(16).

Therefore, it is possible to build LNG pipeline by only straight pipe without loop piping adopting Invar Alloy for LNG transportation.

The characteristics of Invar Alloy compared with stainless steel is shown in Table4-1. Invar Alloy has almost the same mechanical characteristics, and never makes brittle fracture under the temperature of LNG.

Table4-1 Characteristics of Invar Alloy

Item	Invar Alloy	Stainless Steel
0.2% Proof Stress (N/mm ²)	≥240	≥205
Tensile Strength (N/mm ²)	≥440	≥520
Elongation (%)	≥ 30	≥ 40
Coefficient of Linear Expansion (×10 ⁻⁶ /K)	1.7	15.0

Invar Alloy has been utilized as the material of CRT shadow mask, the tension member of power transmission cable and the membrane of LNG cargo tank, where the thermal expansion and shrinkage must be avoided.

There is no example that Invar Alloy has been used as the material of structural members, that is why there are not sufficient design data for LNG pipeline and piping although the material characteristic values of Invar Alloy are reported in various papers.

Therefore, the strength and other mechanical properties of Invar Alloy have been investigated, the results of which are shown in Fig. 4-2 and Fig. 4-3.

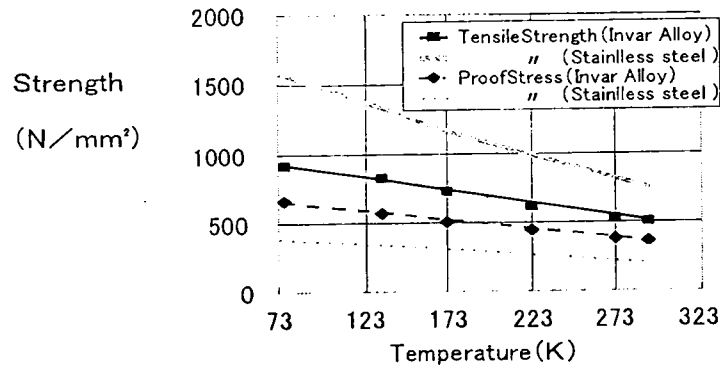


Fig. 4-2 Proof Stress and Tensile Strength

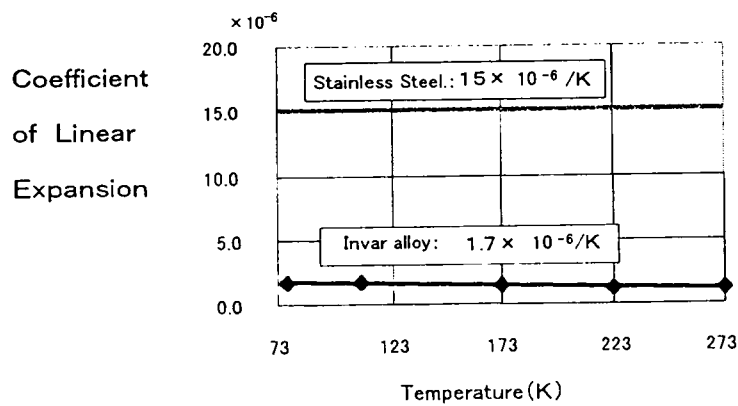


Fig. 4-3 Coefficient of Linear Expansion

(2) Weldability of Invar Alloy

<Mechanism of occurring cracks during multi-pass welding>

It has been pointed out that cracks are often generated in the weld of Invar Alloy during multi-pass welding process. The mechanism of crack generation has been investigated by microstructural observation and high-temperature ductility tests.

By such metallurgical investigations, cracks observed in multi-pass weld of Invar Alloy have been identified as ductility dip cracks, which occurs due to the lowering of the ductility of the weld metal after reheating by the subsequent weld passes.

Furthermore, after the influence of the sulfur (S) content in the weld metal against ductility dip cracks has been investigated, it has been confirmed that susceptibility of ductility dip cracks gets higher as the amount of S. increases.

Based on these results, it has been concluded that ductility dip cracks in the multi-pass welding of Invar Alloy are caused by segregation of S that reduced the bonding strength at the grain boundary (16)(17) (18).

<Prevention of Weld Cracks>

In order to establish a method to prevent ductility dip cracks that occur in Invar Alloy during the multi-pass welding process, the effect of the chemical composition of the weld metal and its mechanism has been examined.

There have been operated a lot of patterns of ductility dip crack tests with various carbon (C) and niobium (Nb) contents. Fig. 4-4 shows the relationship between the ductility dip crack length and the amount of Nb contents.

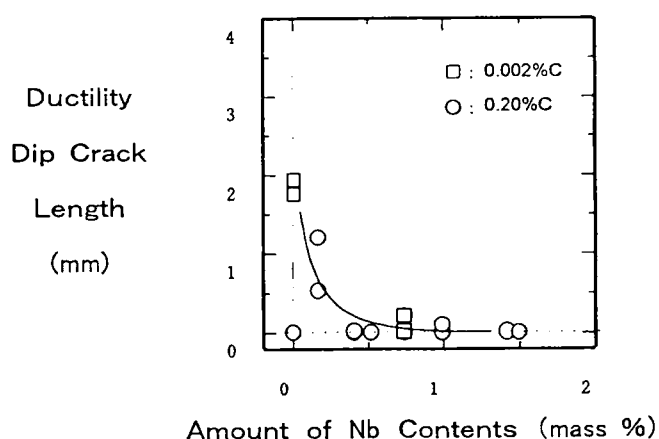


Fig. 4-4 Influence of C and Nb contents against Ductility Dip Crack Length

The occurrence of ductility dip cracks has been confirmed to decrease as the amounts of C and Nb are increased. When these elements are added in adequate complex proportion, the cracks in the weld metal shall be prevented.

From microstructure observations of the weld metal and the results of grain boundary deposit identifications, the reason of the excellent effects of C and Nb against the susceptibility to ductility dip cracks of Invar Alloy has been concluded as below.

- The combined addition of C and Nb makes the crystallization of niobium carbide (NbC) at the grain boundary.
- The area of grain boundary increases by the induced complexity of the grain boundary.
- It reduces both the segregation of S at the grain boundary and the stress concentration at the triple point of the boundary .

(3) Establishment of Welding Procedure

The combined addition of C and Nb in the filler wire shall prevent ductility dip cracks, however, it has been recongnized that the exessive addition of C and Nb makes the ductility under low temperature less. The adequate welding condition that ensures both the prevention of ductility dip cracks and the performance of required ductility under low temperature has been determined quantitatively from experiments using two types of filler wire as shown in Table4-2.

Table 4-2 Chemical Components of Base Metal and Filler Wire (mass%)

Material		C	Si	Mn	P	S	Ni	Nb
Base Metal(9.5mm ^t)		0.003	0.03	0.19	0.005	0.001	35.99	—
Filler Wire (1.2mm ϕ)	H 1	0.23	0.03	0.20	0.001	<0.001	36.44	0.80
	H 2	0.22	<0.01	0.12	0.001	<0.001	35.98	1.61

As shown in Fig. 4-5 Multi-Pass GTAW has been executed on Invar Alloy plates with U-shape groove in the following welding conditions.

- The welding conditions of the first layer and the second layer indicated by shaded area in the figure are constant.
- Heat input and Wire feeding rate of the third layer and the subsequent layers are changed in some range.

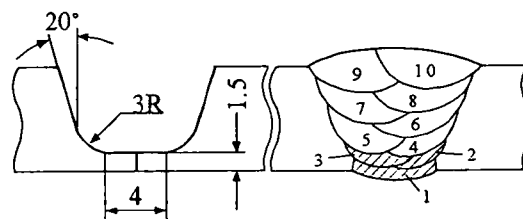


Fig. 4-5 Groove and Layers

Fig. 4-6 shows the results of experiments when the all layers are welded using the wire of low Nb contents (Filler Wire : H1).

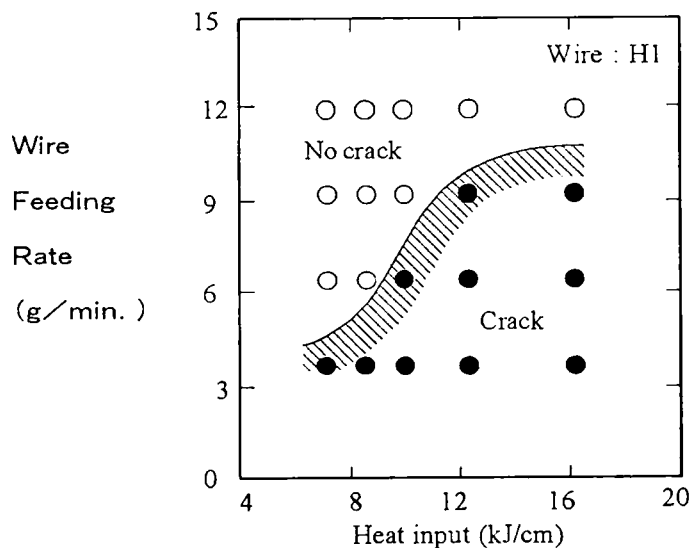


Fig. 4-6 Occurrence Region of Ductility Dip Cracks(H1)

In this case of low Nb contents, ductility dip cracks occur if the heat input is relatively high and the wire feeding rate is relatively slow.

The cracks are supposed to generate because C and Nb has been diluted in the bottom of U-shape groove.

On the contrary, there has never occurred any crack when the third and the subsequent layers are welded using the wire of low Nb contents(Filler Wire : H1) on the first and second layers welded using the wire of high Nb contents(Filler Wire : H2) as shown in Fig. 4-7.

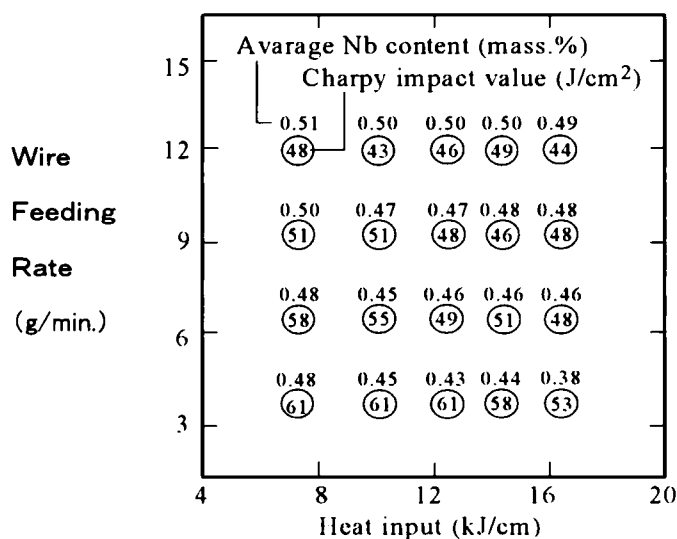


Fig. 4-7 No Ductility Dip Cracks with Combination of H1 and H2

In the figure above the Charpy impact values are obtained in the test temperature of 77K (−196°C), and the values are large enough to be used for LNG pipeline and piping.

Based on these results, standard Invar Alloy welding procedures have been established for both longitudinal and circumferential welding.

4. 2 Evaluation of Safety of Invar Alloy Piping

(1) Evaluation in Model Piping

Evaluation of the safety of Invar Alloy piping has been performed in the model piping(300 A x 20 m) with cooling by liquid nitrogen as shown in Fig. 4-8.



Fig. 4-8 Test Piping of Invar Alloy

The stress has been measured at various parts of this piping model during a process of repeated cooling and heating with pressurizing. It has been verified that there is no progressive increase of strain and the stress of the all positions is within the allowable value.

(2) Establishment of Non-Destructive Inspection Method

Because the accuracy of flaw detection by RT will change owing to the difference of material itself, the reliable inspection method of Inver Alloy must be established considering large amount of radiation damping characteristics of high Ni alloy steel.

Through experiments of RT for various artificial flaws, reliable standards of RT method for Inver Alloy have been established which provide the same flaw detection accuracy as that for stainless steel.

(3) Application to Actual Piping

After the material, the welding procedure and the non-destructive inspection has been established, practical application was executed in the LNG terminal in 2001.

Fig. 4-9 shows the completed piping facilities using Inver Alloy which has been operated without any troubles.

The establishment of this system will make LNG pipeline and piping more efficient and economical in the future.



Fig. 4-9 Application to Actual Piping in LNG Terminal

Chapter 5 Development of New Heat Insulation Pipeline System

For the purpose of effective energy utilization, the heat energy born in heat sources has been transported to the demands by pipeline in a lot of areas.

If the site has enough space to place the heat-transport pipeline, the usual method with heat insulation could be executed. Piping in utility tunnels and exclusive-use tunnels is also under the same condition.

In the other places where the site is not so wide to install insulated pipeline, double-pipe method with heat insulator between mother pipe and casing pipe is usually applied under the ground.

Being required enough strength against heat, heat affected loadings and other outer loadings, steel pipe is adopted for the mother pipe and the casing pipe.

District Heating and Cooling System (DHC) is one of the most effective energy systems, because the demands of heat exist near the source of energy.

This system has been adopted numerously especially in big cities.

In DHC system, the utility tunnels and the exclusive-use tunnels were constructed for pipeline space initially, which cost too expensive to keep the total system feasible.

Therefore, the attention has been focused on Insulation Double-Pipe Systems which is more economical than the former system.

Even after adopting this system, further economical efforts must be accumulated to make the energy fee cheaper for the customers.

In such a circumstance, new double-pipe system for the hot water transportation has been developed.

5. 1 Structure of New Insulation Double-Pipe

To make pipeline transportation system of hot water more economical and durable than the conventional double-pipe system, the following structural concept has been reflected.

- Perfect corrosion protection of mother pipe must be equipped.
- Steel pipe of casing pipe must be eliminated.
- Earth load must be supported by insulator with adequate waterproofing.

The final structure is shown as Fig. 5-1.



Moter Pipe : Polyethylene Lining Steel Pipe(PEL)

Casing Pipe : Polyethylene Pipe(PE)

Insulator : Haed Urethane Form(PUF)

Fig. 5-1 Structure of Economical Insulation Double-Pipe

5. 2 Evaluation of Insulation Double-Pipe

To ascertain the fundamental properties of Insulation Double-Pipe, vertical loading tests and sliding tests have been executed.

(1) Vertical Loading Test

The purpose is to ascertain that the Insulation Double-Pipe endure the outer loadings as restricted in the Law of Heat Supply.

<Vertical Test Specimen>

The size and numbers of the test specimen are summarized in Table5-1 and Fig. 5-2.

Table5-1 Size and Numbers of Vertical Test Specimens

No.	Mother Pipe (mm)					Casing Pipe (mm)				Insu.	Num.
	Pipe	Dia.	O.D.	WT	PE	Pipe	O.D.	WT	I.D.	WT	
1	PEL	150A	165.2	5.0	2.4	PE	261.0	5.5	250.0	40.0	3
2	(SGP)	350A	355.6	7.9	3.7		470.0	10.0	450.0	43.5	3

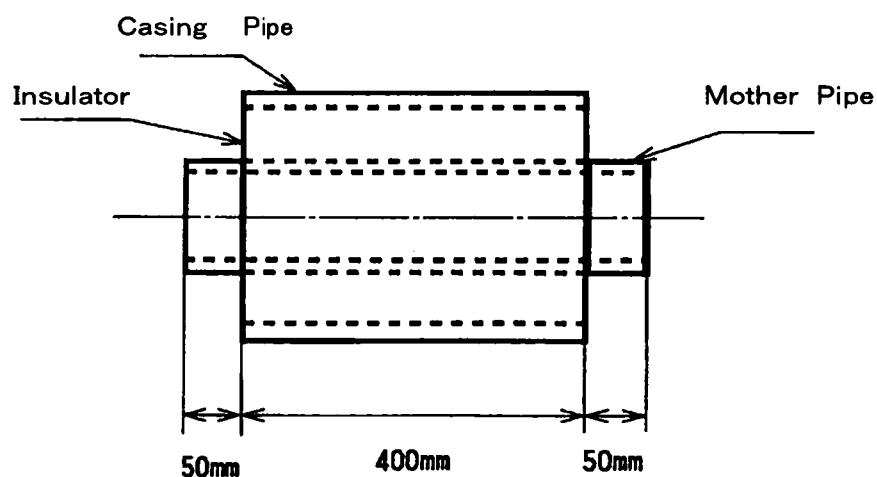


Fig. 5-2 Size of Vertical Test Specimens

<Vertical Loading Experiment>

The vertical loading test has been conducted with the devices and equipment as shown in Fig. 5-3 and Fig. 5-4.

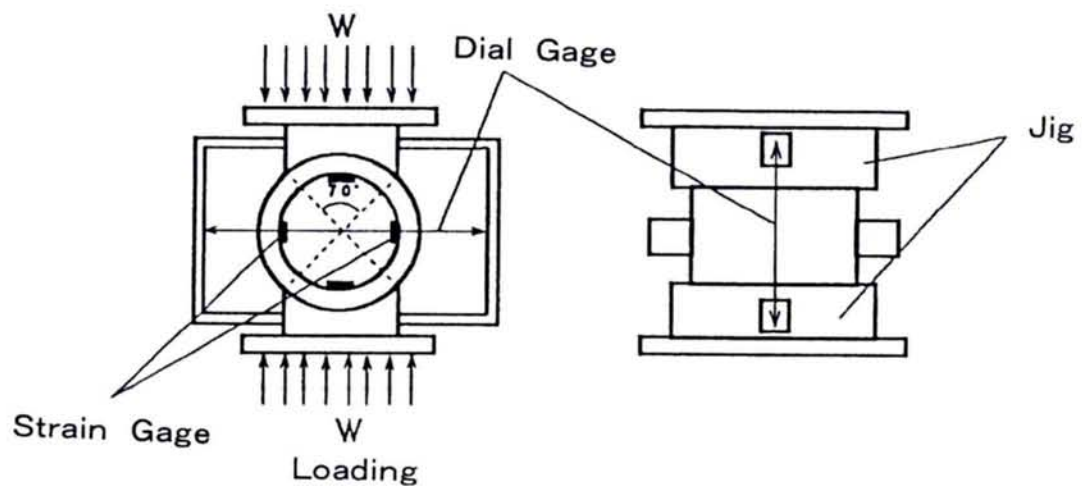


Fig. 5-3 Vertical Loading Test Devices

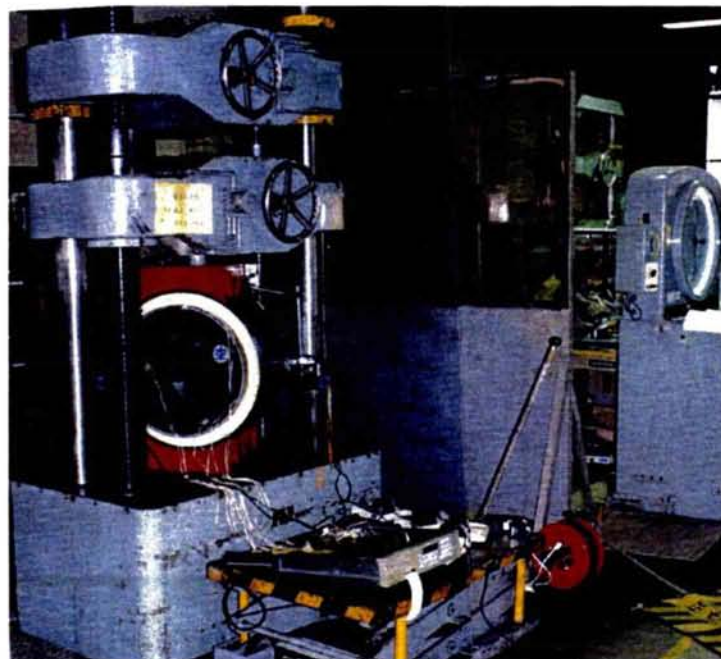


Fig. 5-4 Equipment of Vertical Loading Test

<Results of Vertical Loading Test>

The deformation of the casing pipe, strain and stress of the mother pipe are shown in Fig. 5-5 .

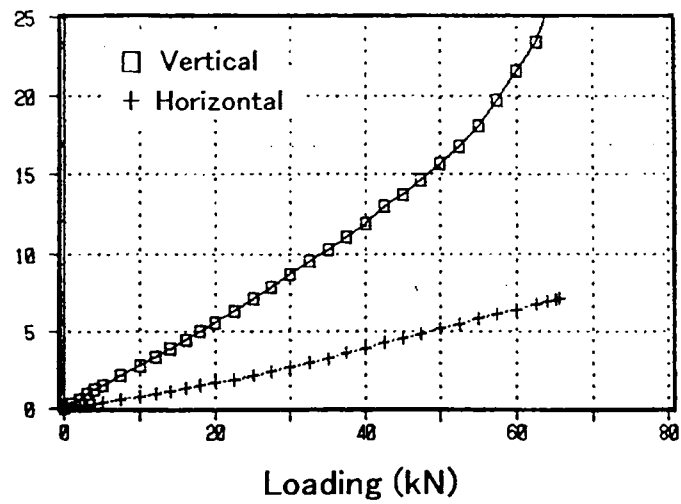
In every figure the deformation, strain and stress increase in proportion to the load approximately until abnormal flatness arises.

This abnormal flatness is obviously caused by break of PUF when the loading gets far larger than considerable loading of buried pipeline.

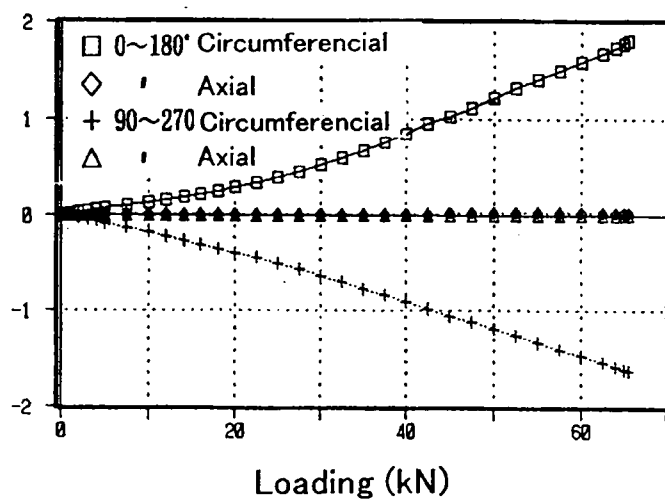
As the deformation of PE pipe is approximately two mm at most in considerable loading region, the strain and stress of mother pipe are neglectably small against the allowance value of steel pipe.

Thus the necessary strength against outer loading restricted in the Law has been ascertained numerically.

① Deformation
of
Casing Pipe
(mm)



② Strain
of
Mother Pipe
($\times 1/1000$)



③ Stress
of
Mother Pipe
(kg/mm²)

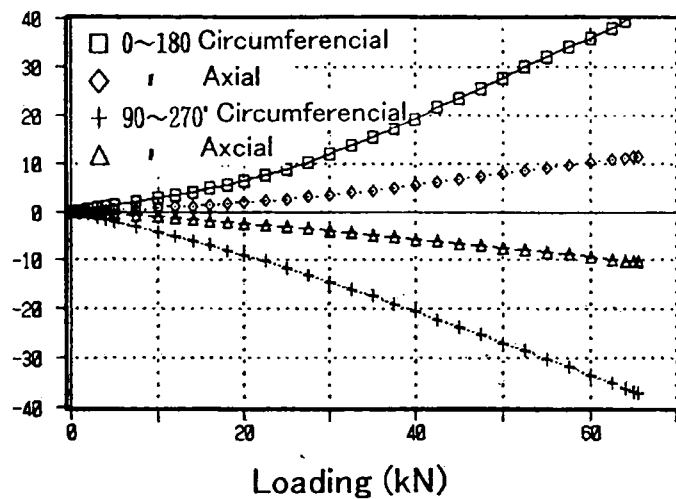


Fig. 5-5 An Example of Vertical Loading Results

(2) Sliding Test

The purpose is to ascertain that the adhesive strength of Insulation Double-Pipe endures the temprature change induced by hot water.

<Slide Test Specimen>

The size and numbers of the test specimen are surmmarized in Table5-1 and Fig. 5-2.

Table5-1 Size and Numbers of Sliding Test Specimens

No.	Mother Pipe (mm)					Casing Pipe (mm)				Insu.	Num.
	Pipe	Dia.	O.D.	WT	PE	Pipe	O.D.	WT	I.D.	WT	
1	PEL	150A	165.2	5.0	2.4	PE	261.0	5.5	250.0	40.0	4
2	(SGP)	350A	355.6	7.9	3.7		470.0	10.0	450.0	43.5	3

<Sliding Test Experiments>

The sliding load has been pressed to the mother pipe contained hot water (60°C) inside as shown in Fig. 5-6 and Fig. 5-7.

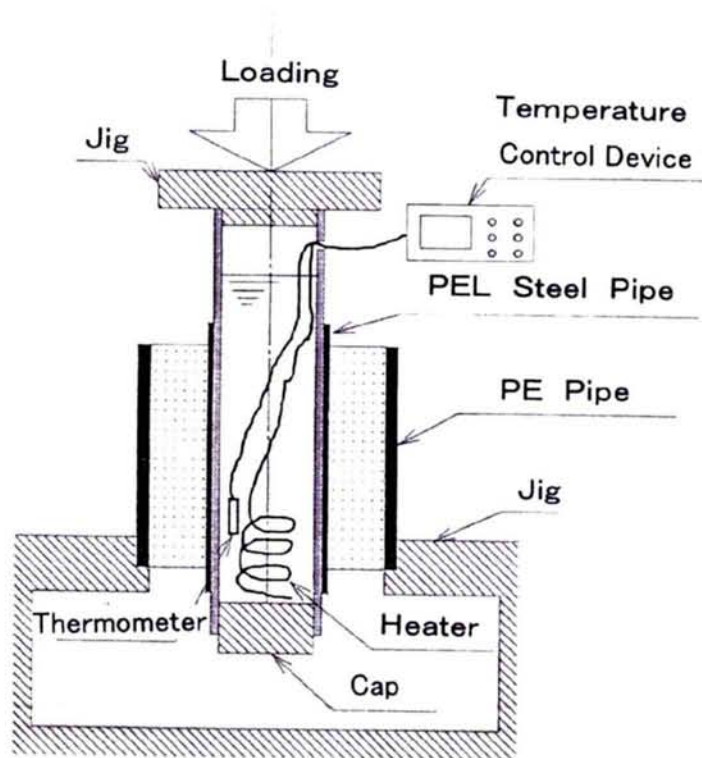


Fig. 5-6 Sliding Test Devices



Fig. 5-7 Sliding Test Equipment

<Results of Sliding Test>

When the hot water has been put into the mother pipe, the behaviors of the both pipe are all the same which has proved that the hybrid pipe behaves as a unit against temperature changes.

The relationship of axial deformation and loading is shown in Fig. 5-8. From this destruction test, it has been ascertained that the final destruction will occur between the PE pipe and PUF in large loading. Of course no slide will occur in small loading region and all the component move as a unit.

In order to check the behavior when a large axial force works to the hybrid pipe, the slide start loading (S) is compared with the friction between the casing pipe and the soil (F) in Table 5-3.

The values of safety factor mean the reliability of the Insulation Double-Pipe because the slide between the casing pipe and the soil will occur first and there will be no damage inside of the hybrid pipe even if relatively large forces act underground.

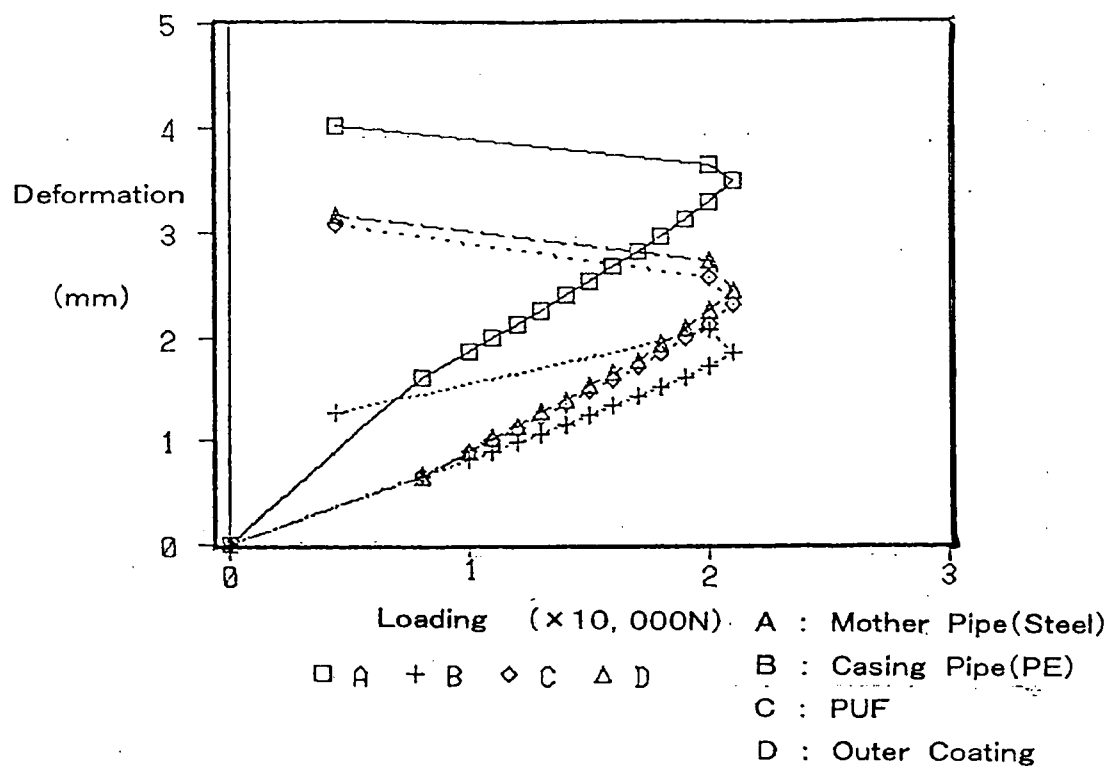


Fig. 5-8 Relationship of Sliding Deformation and Loading

Table5-3 Safety Factor against Sliding

Diameter	Sliding Start Loading (kg/m) S	Friction between Casing Pipe/Soil (kg/m) F	Safety Ratio S/F
150A	4,060	410	9.9
350A	7,440	740	10.1

Chapter 6 Development of Pipeline Maintenance Technology and Devices

One of the main technical themes in the field of existing pipeline is how to check and renew the old facilities to keep the function which was initially equipped.

Because the existing pipeline is so old that there are invisible structural problems owing to deterioration and aging of materials, changing of ground conditions during long service periods.

Therefore, in the work of maintenance of existing facilities, efficient and sure inspection of old ones is very important to prevent from huge accidents.

In that sense, maintenance, inspection and renewal of existing pipeline might be the most significant theme for the future nowadays.

6. 1 Rapid Inspection System of Existing Pipe-Bridges

When the old pipe-bridges are checked and inspected whether the rest wall thickness is sufficient or not, there must be constructed scaffold facilities to make any inspection method in the past.

Therefore, more speedy and economical method to check the rest wall thickness without scaffold facilities has been expected.

This "Rapid Inspection System of Existing Pipe-Bridges" has been developed under such circumstances using remote controlled inspection unit which enabled quick and sure inspection.

(1) Fundamental Principal

The fundamental principal of measuring the rest wall thickness (WT) is shown in Fig. 6-1.

The resting wall thickness can be fixed by measuring propagation time between the first bottom echo and the second one.

In the corrosion portion, however, the same approach is fully in vain because second bottom echo might vanish owing to reflection echo drop as shown in Fig. 6-2.

Therefore in this system, the rest wall thickness has been calculated by subtracting the coating thickness obtained by using electromagnet thickness gage from the total thickness fixed by measuring propagation time between the surface echo (S) and the reflection echo from the corrosion portion.

It becomes possible to measure the rest wall thickness in both sound portion and corrosion portion stably using this system.

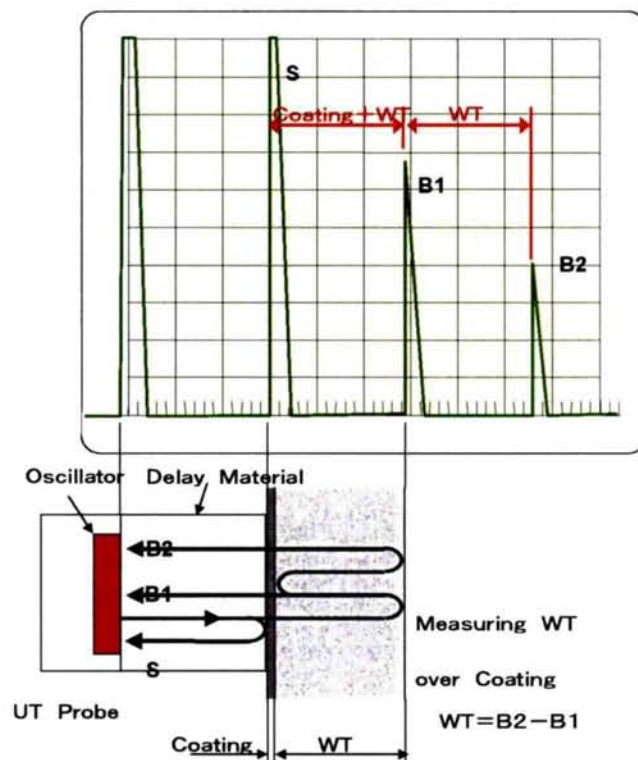


Fig. 6-1 Principal of Measuring Wall Thickness over Coating(Sound Portion)

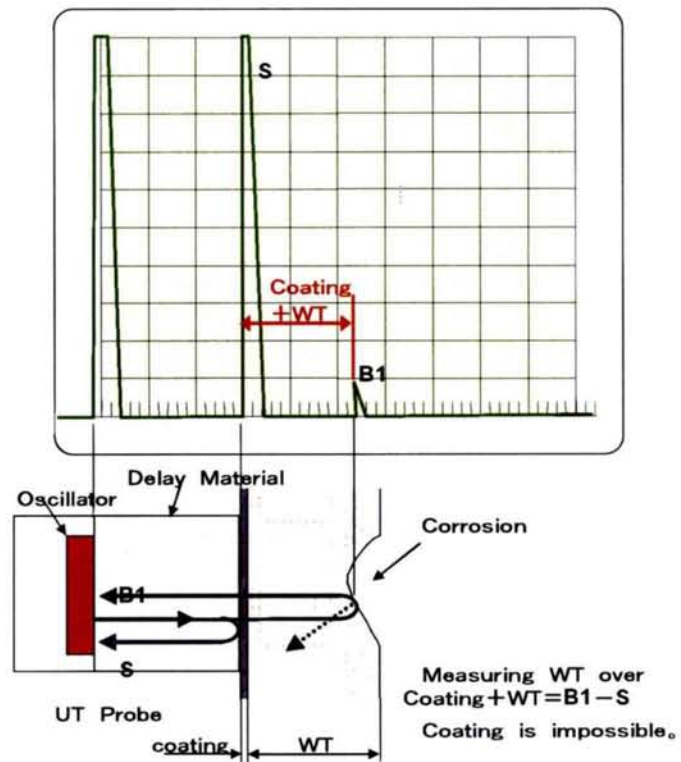


Fig. 6-2 Principal of Measuring Wall Thickness over Coating(Corrosion Portion)

Fig.6-3 shows the structure of the probeholder which contains UT probe and electromagnet thickness gage compactly.

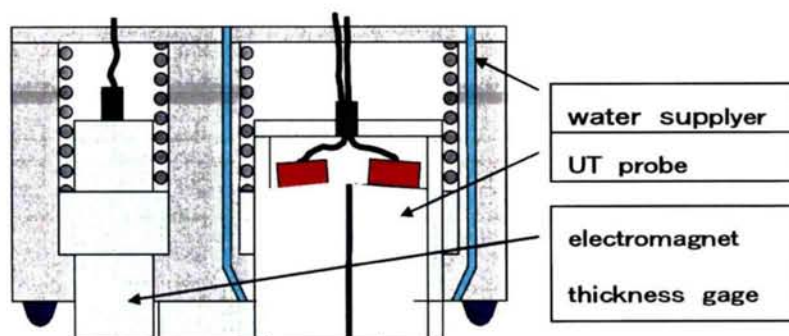


Fig. 6-3 Structure of Probeholder

(2) Outlook of the system

Fig. 6-4 shows the outlook of this system, which is composed of the running and detective devices.

The running device has strong power magnet catarpillar treads in both sides to attach to pipe during running periods.

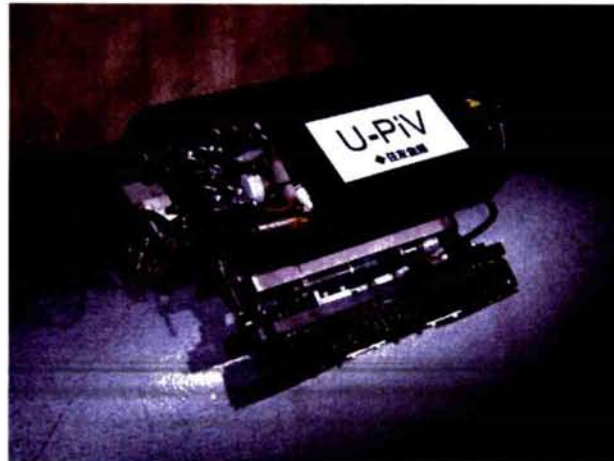


Fig. 6-4 Running and Detecting Device

The control and display device is shown in Fig. 6-5 with controller by which the running and detecting device are remote-controlled on the inspection pipe easily.



Fig. 6-5 Control and Display Device

(3) The features of the system

- Remote control has diminished the expensive scaffold.
- The coating will never hurt.
- Stable running is achieved even on curved surface.
- Simple judgement is possible from the colored screen.

(4) Evaluation Test

Evaluation test has been executed under the conditions in Table6-1.

Table6-1 Conditions of Evaluation Test

Item	Specification
Specimen	500A × 6.9mm ^t
Shape of Artificial Defect	φ 50 Sphere
Depth of Artificial Defect	4.0mm & 2.2mm
Standard Value	Measured before Coating by UT Thickness Gauge

And the results summarized in Table6-2 show the accuracy of this system.

Table6-2 Results of Evaluation Test

Depth of Artificial Defect	Standard Value	Measured Value
4.0mm	4.1mm	4.1mm
2.2mm	2.2mm	2.3mm

Fig. 6-6 is an example of measured output data by the system.

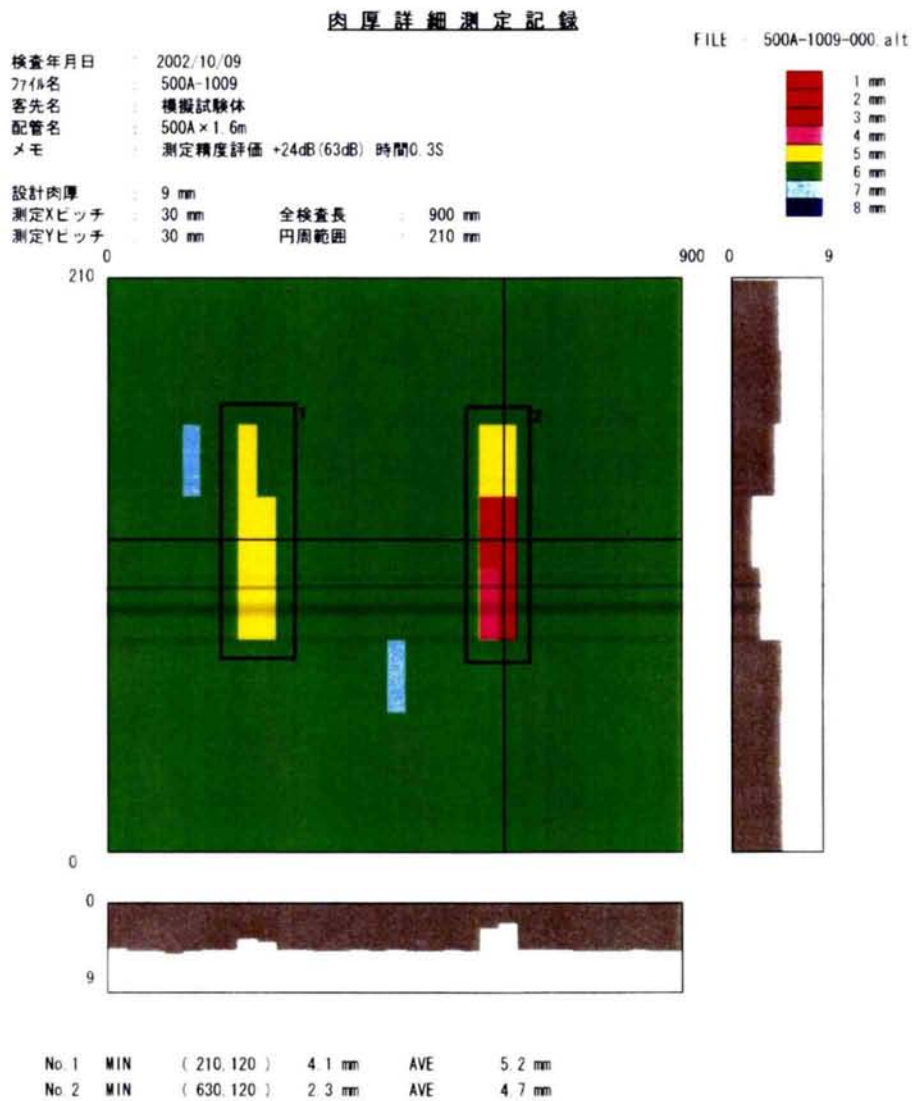


Fig. 6-6 An Example of Output Data

(5) Field Evaluation Test

The field monitor test has been executed in the conditions shown in Table6-3.

Table6-3 Field Test Conditions

Diameter and WT	$\phi 700 \times 6.0\text{mm}^{\dagger}$
Inspection Area	600~1800mm Distance from Riverbank
Mesuring Pitch	30mm Pitch

Fig. 6-7 shows the scene of the field test, and Fig. 6-8 shows the result of inspection.

Applicability and Operativity of the system has been ascertained in the actual pipe bridge.



Fig. 6-7 Remoto Control Running and Inspection

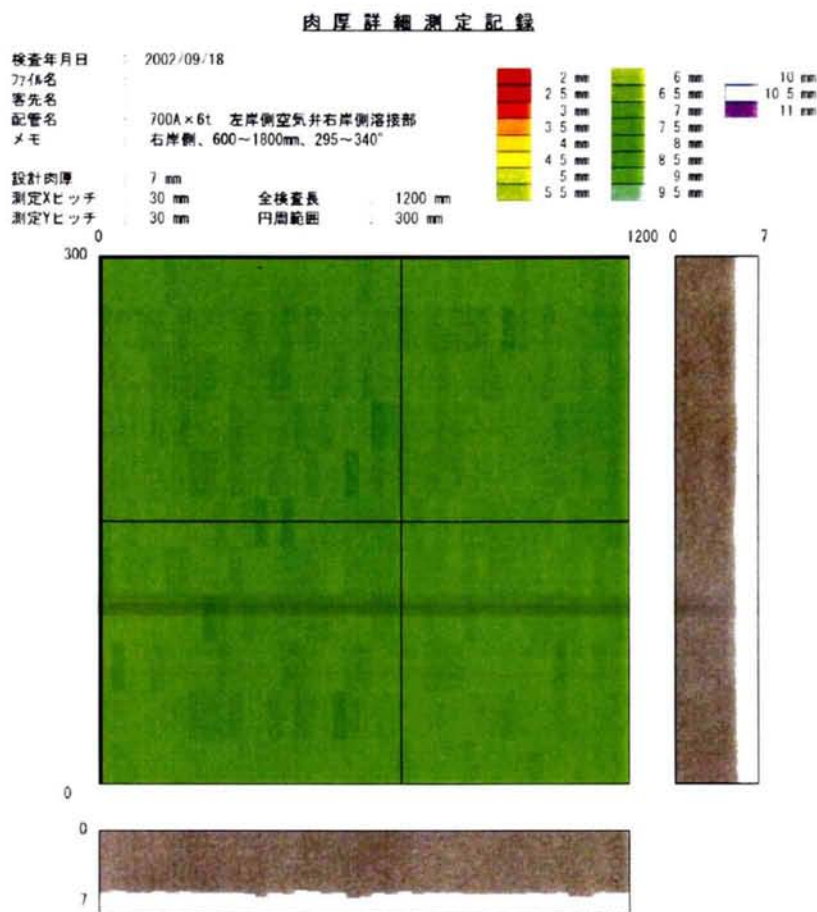


Fig. 6-8 An Example of Field Test Output Data

6. 2 Advanced Pipeline Coating Inspection System

Usually the outside of the steel pipeline is executed anti-corrosion coating to prevent from any corrosion.

Although the electric protection is also executed, the soundness of the outer coating is a very important item to keep the pipeline safe for a long term.

As the pipeline is buried underground, the Electric Potential Method is adopted to check the defect of the outer coating.

In order to raise the accuracy of this method, the advanced inspection method with magnetic field synchronization has been developed.

(1) Fundamental principle

When the probe current is burdened to existing buried pipeline, some electric potential of the ground surface is formed by the leak current from the defects of the outer coating.

It is possible to detect the defects of coating by measuring electric potential difference of the ground surface. The most efficient way of measuring is Rotary Electrodes Procedure where continuous measuring of the electric potential difference between the two adjacent rotary electrodes can be made easily.

If there is any defect, the phase of detected electric potential turns over and zero-cross exactly just above of the point of the defect as shown in Fig. 6-9.

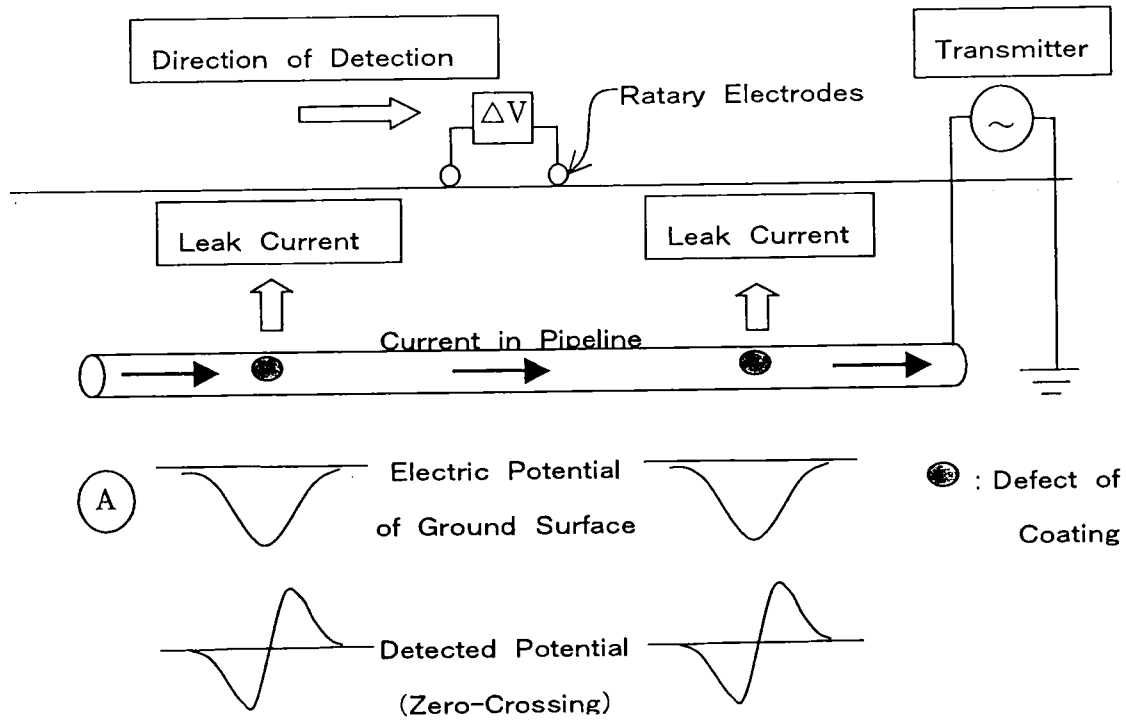


Fig. 6-9 Fundamental Principle of Coating Inspection System

Numatically the electric potential of against infinite-point is calculated as follows(19).

$$V = \frac{\rho i}{4\pi} \left\{ \frac{1}{\sqrt{x^2 + y^2 + (z-d)^2}} + \frac{1}{\sqrt{x^2 + y^2 + (z+d)^2}} \right\} \dots \quad (1)$$

where

V : Electric Potential (V)

ρ : Soil Ratio Resistance ($\Omega \cdot m$)

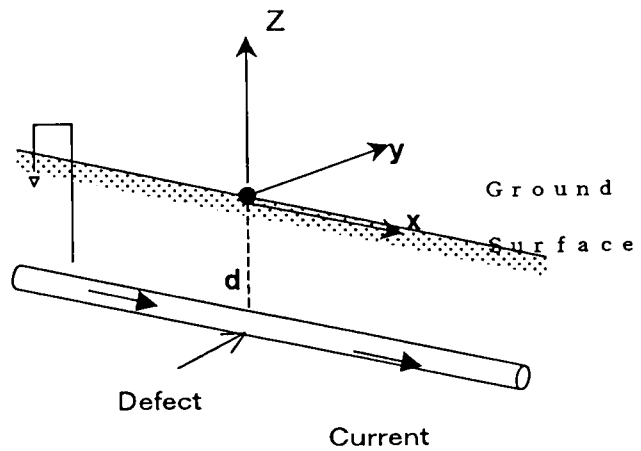
I : Leak Current (A)

X : Distance from Defect
along X Axis (m)

y : Distance from Defect
along Y Axis (m)

z : Distance from Defect
along Z Axis (m)

d : Depth of Defect (m)



The Electric Potential of the Ground Surface (V) can be obtained by Equation② as bellow.

$$V = \frac{\rho i}{2\pi} \frac{1}{\sqrt{x^2 + y^2 + d^2}} \dots \quad (2)$$

The electric potential difference of roraty electrodes is calculated by Equation③.

The defect area (S) is also calculated from Equation ③, ④and⑤.

$$\Delta V = \frac{\rho i}{2\pi} \left\{ \frac{1}{\sqrt{(X + \frac{L}{2})^2 + Y^2 + d^2}} - \frac{1}{\sqrt{(X - \frac{L}{2})^2 + Y^2 + d^2}} \right\} \dots \quad (3)$$

$$R = \frac{E}{i} \dots \quad (4)$$

$$R = \rho \left(\frac{t}{S} + \frac{1}{\sqrt{2\pi S}} \right) \dots \quad (5)$$

where

R : Ground Resistance (Ω)

t : Thickness of Coating (m)

S : Defect Area (m²)

E : Altenating Electrical Potential of Pipeline (V)

ΔV : Electric Potential difference (V)

ρ : Soil Ratio Resistance ($\Omega \cdot m$)

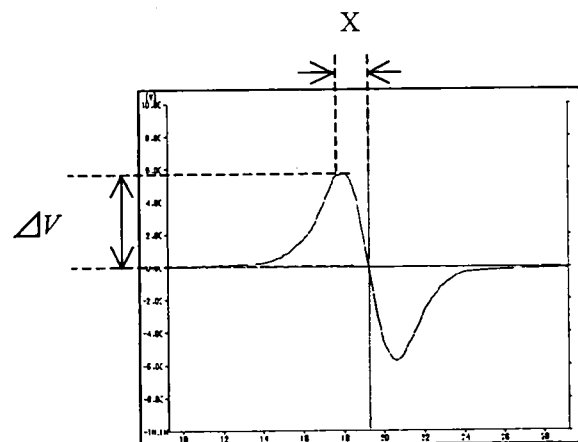
i : Leak Current (A)

X : Peak Position of Electric Potential (m)

L : Distance between the Electrodes (m)

Y : Distance from Pipeline (m)

d : Defect Depth (m)



Obtained Data

(2) Advanced devices

Although the coating inspection by Rotary Electrodes Procedure is already established theoretically, various kinds of leak current make actual inspection analyses very difficult in fact.

The Pipeline Antenna Method has been developed as one of the most effective measures against the leak current, in which the magnetic field occurred by alternating current of existing pipeline is detected by the high-sensitive loop coil equipped to the measuring car as shown in Fig. 6-10.

If there is any defect, the phase of defect signal will also turn over at the point of injured coating in the magnetic field.

And otherwise, in case of no defect, no turning over will be gain.

Thus the detected zero-crossing signal in the electrical field can be checked by synchronized data in the magnetic field whether the zero-crossing is really induced by any defect or not.

Direction of Detection

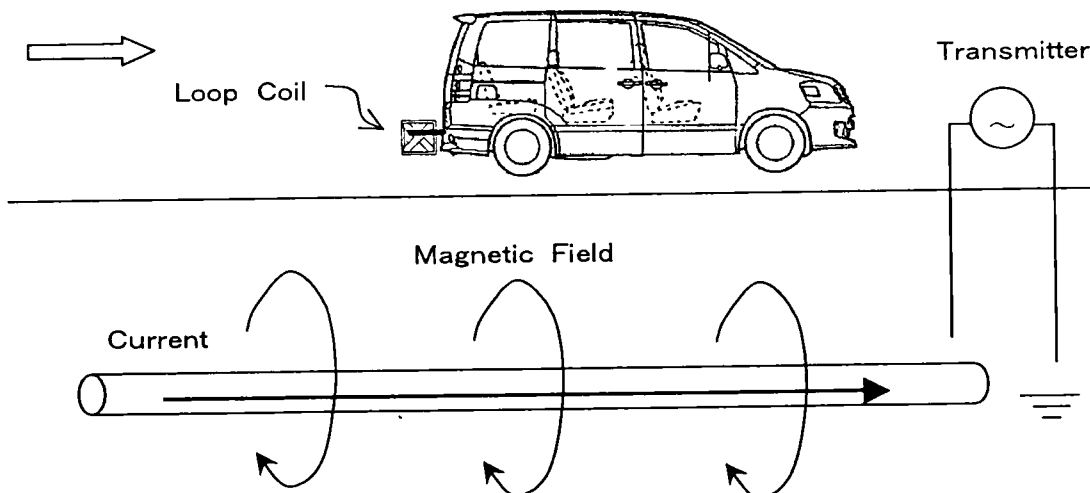


Fig. 6-10 Outline of Pipeline Antenna Method

6. 3 Economical Pipe Renewal Systems

6. 3. 1 Pipe in Pipe System

For relatively large diameter pipeline where pipefitters and welders can work, Pipe in Pipe System by steel pipe is an effective conventional renewal way of water pipeline.

In this renewal system the new steel pipe is namely inserted into existing pipeline, where conveyance, pipefitting and welding procedure is executed in the existing pipeline.

While this system has the advantage of non-dig style, the reduction of the diameter may be the worst problem from the viewpoint of keeping the flow quantity.

Under such a circumstance, Half-Finished Pipe Insertion System has been developed to make the diameter of inserted pipeline larger.

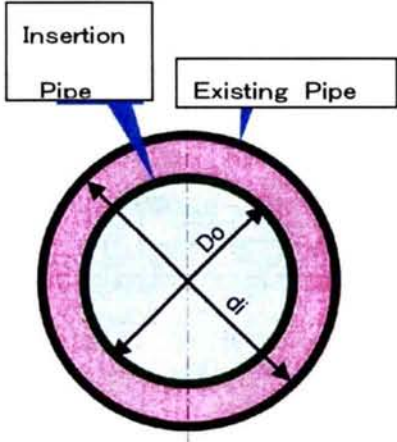
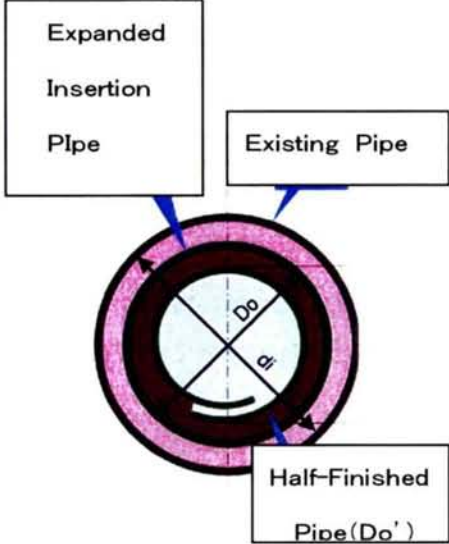
In this new system, the new pipe is rolled up to be smaller diameter without seam welding before insertion, then the unroll and seam weld will be executed in the existing pipeline as a next stage.

Although the work period and man hours get far more owing to the increase of field welding work, the diameter of Half-Finished Pipe Insertion System can be designed larger than that of Conventional Pipe Insertion System by about two inches.

Table6-4 shows the abstract of Conventional Pipe Insertion System and Half-Finished Pipe Insertion System, respectively.

Half-Finished Pipe Insertion System is supposed to increase from now on, because the capacity of flow quantity is fixed by the diameter of inserted pipe.

Table6-4 The Abstract of Pipe in Pipe System

Item	Conventional Pipe Insertion System	Half-Finished Pipe Insertion System
Outlook	 <p>The diagram shows a cross-section of a conventional pipe insertion system. It consists of an outer 'Existing Pipe' with diameter d_i and an inner 'Insertion Pipe' with diameter D_o. The insertion pipe is shown as a solid light blue circle within the pink-shaded annulus of the existing pipe.</p> <p>D_o : Diameter of insertion pipe d_i : Diameter of Existing pipe</p>	 <p>The diagram shows a cross-section of a half-finished pipe insertion system. It features an outer 'Existing Pipe' with diameter d_i, an inner 'Expanded Insertion Pipe' with diameter D_o, and a 'Half-Finished Pipe (D_o')' with diameter D_o'. The half-finished pipe is shown as a thin pink ring between the expanded insertion pipe and the existing pipe.</p> <p>D_o' : Diameter of insertion half finished pipe D_o : Diameter of expanded insertion pipe d_i : Diameter of Existing pipe</p>
Field Welding	Girth Weld —	Seam Weld Girth Weld
Insertion Pipe Size	One Size Up or smaller one size : 100mm	Half Size Up or smaller half size : 50mm

The reduction ratio of flow quantity obtained as the quotient of the flow quantity of insertion systems (Q_1, Q_2) divided by that of the existing pipeline is shown in Fig. 6-11.

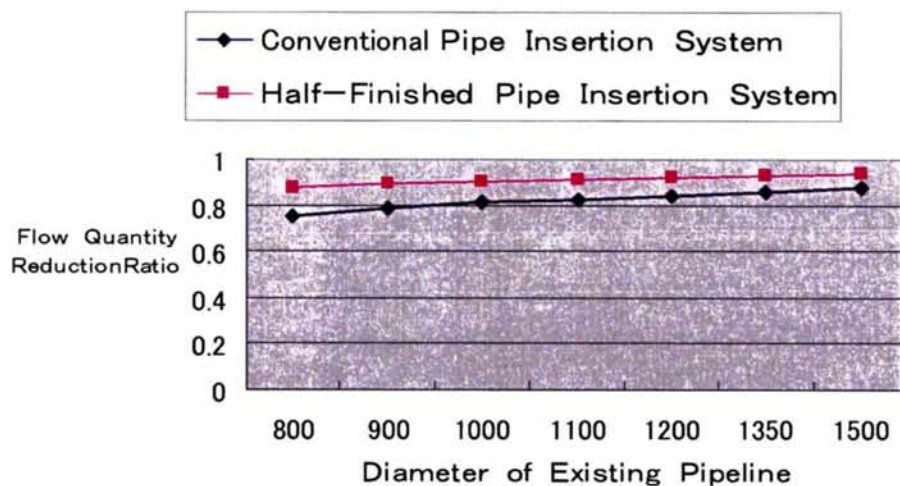


Fig. 6-11 Reduction Ratio of Flow Quantity

In both systems the reduction ratio gets greater in proportion to the existing pipe diameter.

The improvement of the reduction ratio adopting Half-Finished Pipe Insertion System is calculated as the quotient of its flow quantity (Q2) divided by that of Conventional Pipe Insertion System (Q1) in Fig. 6-12.

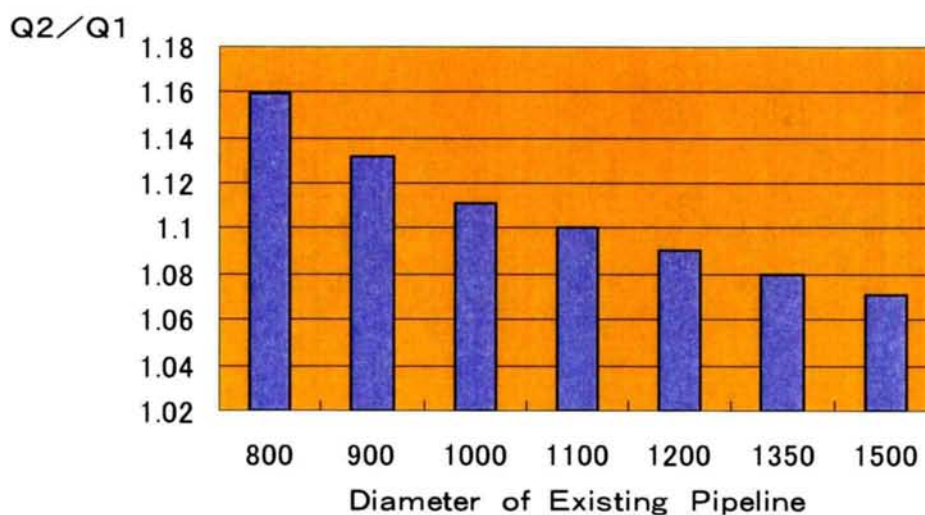


Fig. 6-12 Proportion of Flow Quantity : $Q2/Q1$

It is obviously recongnized that the smaller the diameter of existing pipeline is, the larger the superior of Half-Finished Pipe Insertion System is.

The manufacturing of Half-Finished Pipe is shown in Fig. 6-13.

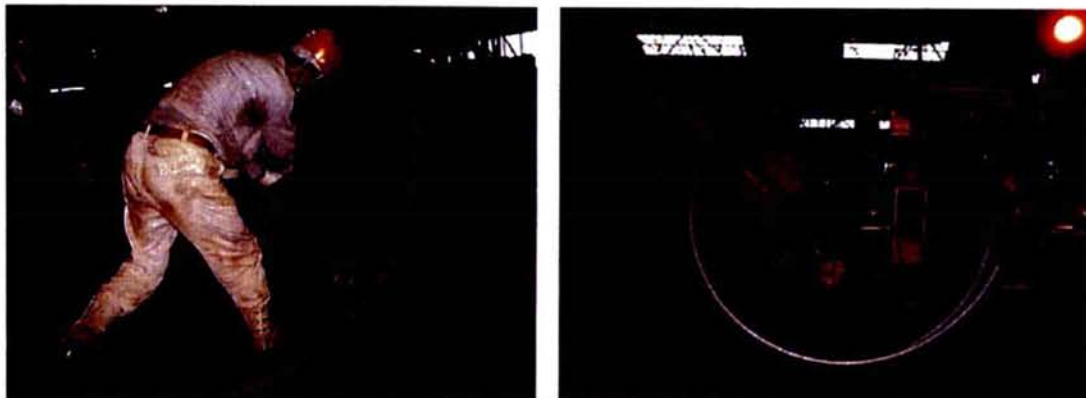


Fig. 6-13 Manufacturing of Half-Finished Pipe

6. 3. 2 Polyethylene Pipe Insertion System

For the pipeline of which the diameter is smaller than 800mm, Pipe in Pipe System is impossible to be executed.

There have been developed a lot of renewal systems which can be adopted for pipeline with small diameter so far.

Among such renewal systems Subterra System is one of the most reliable polyethylene insertion systems because the polyethylene pipe inserted into existing pipeline can endure the outer loading itself.

This system has been developed in England in 1985.

And there have been executed in the field of waterworks, sewerage and water for industrial use.

By using Heart-Shape processing of insertion pipe shown in Fig. 6-14, long-distance insertion over 1, 000m has been achieved.



Fig. 6-14 Heart-Shape processing of insertion pipe

This system have not be adopted in Japan, however, the practical executing data has been piled up.

It will be adopted soon by backing the renewal needs of existing pipeline in the near future.

Chapter 7 Conclusions

The intention of this study is the development and application of advanced pipeline systems especially in Japan, where the progress of pipeline is obviously inferior to the other advanced countries.

Natural gas should be utilized more quantitatively from the viewpoint of energy liberalization and environmental protection, the transportation of which will get more efficiently and economically by technical proposals for pipeline in Chapter 2, 3, and 4.

In Chapter 5, reliable insulation pipe and pipeline system is proposed for the purpose of effective transportation of heat energy. And in the field of facility renewals, excellent inspection and maintenance systems of existing pipeline are proposed in Chapter 6.

The following conclusions are summarized in this study.

In Chapter 2, modernized automatic construction systems and the their combination have been developed and evaluated experimentally, almost of which have been executed in practical use.

Automatic Welding System has been developed especially for relatively large diameter high-pressure natural gas pipeline, which has made the quality of the welding much better and the cost more economical as well. The executing welding machine has been gotten of some varieties according to the field conditions by changing the number of the welding head, the angle of the groove and the control systems.

Automatic Ultrasonic Inspection System has been developed, and which is going to be executed in combination with Automatic Welding System on the background of its authorization in the Gas Utility Industry Law by The Ministry of Economy, Trade and Industry on April 1st, 2004.

Automatic Site Coating System has made the quality of field coating higher and more steady, which used to depend fully upon the skills of pipefitters without established methods of inspection.

Automatic Welding System, Automatic Ultrasonic Inspection System and

Automatic Site Coating System and their combination have completely changed the construction style of natural gas pipeline, which might be a hystorical innovation.

Economical Non-Dig Construction System has been also developed to make the construction of pipeline more speedy and economical. Further safe and sure device and method which make the pulling of pipe into the pushed hume-pipe of small diameter has been also developed.

In Chapter 3, the advantage of high-pressure supply of natural gas has been calculated based on the past construction experiences, where the technical preparation for high-pressure supply has been already made. In the feasibility study it has been supposed that the cost reduction of of higher pressure might get more than twenty percentage. The stream of dereguration in the law will make the trend more active soon.

In Chapter 4, new LNG Pipeline System using Inver Alloy has been developed, the distinguished properties of which are the toughness and the small expansion in low temperature. Inver Alloy has not been used as the structural member so far, however, the material, the welding and the inspection has been developed and established based on numerous experiments and analyses.

This system is especially advantageous when the pipeline is relatively long or its laying space is too narrow because of no pipe loops for stress relaxation.

In Chapter 5, new Heat Insulation Pipeline System for hot water has been developed. The characteristics of the hybrid pipe against outer loadings have been ascertained by experimental proofs, which show the reliability and safety of this system. The cost reduction effect of this system compared with the conventional steel-double-pipe system might be about thirty percentage, therefore, the usage of surplus heat energy might be more promoted to surrounding areas around heat sources.

In Chapter 6, pipeline maintenance technology and devices have been developed to check and renew the existing pipeline.

Rapid Inspection System of Existing Pipe-Bridges has been developed in order to make rapid and approximate wall thickness inspection without any scaffold. Remote controlled device with strong power magnet caterpillar treads, which runs on the pipe with no damage for outer coating, gets precise data of corrosion. And test results can be easily obtained on display device.

The accuracy of coating damage inspection of underground pipeline has been raised up by synchronizing with magnetic data induced alternating current in Advanced Pipeline Coating Inspection System. Half-Finished Pipe Insertion System and Polyethylene Pipe Insertion System have been developed as non-dig renewal piping systems, which enable the conditions of existing pipeline almost as same as those of initial stages.

Through the several proposals and conclusions concerning pipeline, the spread and expansion of pipeline transportation systems shall make more progress in both quality and quantity, which must be the urgent demand for further prosperity of the people and the nation. Practical applications of these developments and further investigations should be necessary to achieve more efficient and reliable pipeline transportation systems.

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